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THESIS

UNITED STATES MARINE CORPS; (USMC) KC-130J TANKER REPLACEMENT REQUIREMENTS AND COST / BENEFIT ANALYSIS

by

Mitchell J. M[c]Carthy

December 1999

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NAVAIR funded a research project to answer the question: how many KC-130Js Aerial Refueling Tankers will the U.S. Marine Corps (USMC) need to meet their future wartime requirements? This thesis supports that study. Thesis results were incorporated into the recently completed Marine KC-130 Requirements Study, by Professors Gates, Kwon, Washburn, and Anderson.

Specifically, the thesis focuses on the tradeoffs the USMC faces between requirements, performance, and life-cycle costs. The KC-130J aerial refueling requirement must support expected USMC fixed-wing refueling demand during two nearly simultaneous major theater wars. Furthermore, refueling capacity must keep the average time an aircraft waits in the aerial refueling queue (CT_q) below five minutes. To define the tradeoff between the KC-130J requirement and system performance (waiting time), the thesis develops a Simulation Model using the ARENA© simulation language. The simulation model highlights the impact of capacity failures (refueling drogues and hoses) and overlaps between KC-130J sorties, two potentially significant factors that can't be explored with standard static queuing theory models. Next, the thesis develops a Life Cycle Cost (LCC) Model that incorporates cost variability using the Crystal Ball EXCEL© spreadsheet add-on. The model defines the tradeoffs between LCC and KC-130J fleet size. The resulting analysis and conclusions specify a base-case KC-130J requirement and discuss the tradeoffs between the requirement, life-cycle cost and system performance.

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UNITED STATES MARINE CORPS; (USMC) KC-130J TANKER REPLACEMENT REQUIREMENTS AND COST / BENEFIT ANALYSIS

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

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NAVAIR funded a research project to answer the question: how many KC-130Js Aerial Refueling Tankers will the U.S. Marine Corps (USMC) need to meet their future wartime requirements? This thesis supports that study. Thesis results were incorporated into the recently completed Marine KC-130 Requirements Study, by Professors Gates, Kwon, Washburn, and Anderson.

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LIST OF SYMBOLS

λ	Arrival Rate
t_s	Average Service Time
μ	Capacity
K	Number of Channels
t_a	Inter-Arrival Rate
P_0	Probability that there are no units in the system
ρ	Utilization

LIST OF ACRONYMS

AR	Aerial Refuel
ARCP	Aerial Refuel Control Point
DASC(A)	Direct Air Support Control (Air)
FMF	Fleet Marine Force
LCC	Life Cycle Costs
MTW	Major Theater War
NPV	Net Present Value
RGR	Rapid Ground Refueling

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I. INTRODUCTION

A. BACKGROUND

In fiscal year 1998 (FY98), the United States Marine Corps (USMC) began to transition to a newer re-engineered KC-130 platform, the KC-130J, in order to replace its aging KC-130 F/R Aerial Refueling Tanker Fleet. However, as the USMC began to make the transition, a question arose concerning the KC-130J fleet size, particularly what fleet size the USMC would need to support future aerial refueling (AR) mission requirements. Hence, a study was directed to ascertain the requisite fleet size the USMC would need to support a dual MTW.

B. PURPOSE

This study provides Marine planners with a decision making tool to support the KC-130J fleet size decision. This decision making tool will use two different simulation programs. One that simulates the physical twenty-four hour a day refueling mission executed by a KC-130J Division during a single MTW and the second, which applies variability to a KC-130J Life Cycle Cost (LCC) EXCEL® spreadsheet. The combined output of these two simulation models will provide the Marine planner with a range of options concerning the fleet size requirement driven by the physical simulation model and then ascribe cost as a factor of that fleet size.

C. SCOPE

This study will provide insight into the size requirements for a future USMC KC-130J fleet. This will not include the use of Joint or Allied tanker aircraft. The exclusion of Joint and Allied aerial tanker assets is deliberate, this study is intended to examine if the indigenous USMC tanker fleet can meet the USMC aerial refueling requirements.

The use of Joint or Allied refueling platforms simply lies beyond the scope of this study.

This study will begin by applying a simple queuing theory model to the KC-130Js primary mission to provide tactical aerial refueling service to Fleet Marine Force (FMF) in a particular theater of operation. We will ascribe numerical values to certain variables, which have a dramatic effect on how many aircraft may be waiting to be refueled ($\mathbf{INV_q}$) and / or how long an aircraft may have to wait to be refueled ($\mathbf{CT_q}$)[1]. By capturing these values we decide the number of KC-130J tankers we will need to support the AR requirement in a certain theater. Secondly, a simulation model will be created which will parallel the essential elements and variables that effect a division of KC-130Js as they perform a twenty-four hour a day refueling mission during a single Major Theater War (MTW) scenario[2].

This simulation model will glean three crucial variables: the average number of aircraft waiting to be refueled ($\mathbf{INV_q}$), the average time combat aircraft spend waiting to be refueled ($\mathbf{CT_q}$), and the average number of KC-130Js actually performing the refueling mission. The fleet sizing decision will be based on the target level for those variables emphasizing the time aircraft spend waiting to be refueled. After analyzing the results from the simulation model, the Marine planner can derive a KC-130J Fleet size that will minimize the amount of time combat aircraft spend waiting to be refueled. Once the fleet-size for an MTW scenario is determined, simple multiplication can derive a fleet size which

---

[1] Conventional notations depict $\mathbf{INV_q}$ as $\mathbf{L_q}$ and $\mathbf{CT_q}$ as $\mathbf{W_q}$, the author chose to use $\mathbf{INV_q}$ (Inventory of the Queue) and $\mathbf{CT_q}$ (Cycle Time of the Queue) because these would more adequately describe the process.

[2] KC-130 Tactical Manual NWP 3-22.5-KC-130, Volume I, NAVAIR 01-75GAA-IT, May 1997, Department of the Navy, Office of the Chief of Naval Operations, pp. 3-35 – 3-39.

will support a near simultaneous dual MTW scenario. Now that the Marine Planner has captured the number attributed to the fleet size, costs can be ascribed to that number.

Thirdly, by plugging the fleet size number into the Life Cycle Cost (LCC) spreadsheet, the LCC cost for the KC-130J fleet can be captured. Variability will be embedded into both the simulation model and the LCC spreadsheet in order to capture the uncertainty resident within any decision process. These two models will work together to provide an effective picture of how a future KC-130J Fleet might be sized and the cost figure attributed to that size.

Fourthly, a chapter will be devoted to executing multiple iterations of the simulation at the highest refueling usage rate, as estimated by a Center for Naval Analysis (CNA) study, to obtain solid fleet size numbers.[3] Plugging those fleet size numbers into the LCC spreadsheet will estimate the total cost for that fleet size. Thus, a range will be derived ascribing fleet size to a cost figure, with the fleet size driven by the required minimum time combat aircraft spend waiting to be refueled. Other variables, such as refueling queue size or the average number of KC-130Js actually performing the refuel mission, will help to validate the model as well as better define the tradeoffs the Marine planner must make (Cost / Benefit Analysis). Marine planners must balance the tradeoffs between fleet size, costs, and the time a combat aircraft waits to be refueled ($\mathbf{CT_q}$). Waiting time prevents combat aircraft from executing their primary mission.

The fifth chapter will be devoted to a Cost / Benefit Analysis of the data gathered from the simulations, providing some cogent conclusions and recommendations to aid the USMC in arriving at the best value

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[3] Cox, Gregory, USN/USMC Tanking Requirements, Center for Naval Analysis, May 95, p.7.

decision. Finally, the last chapter will be dedicated to the study's recommendations and conclusions based on the analysis in the previous chapter.

D. METHODOLOGY

This thesis will mainly discuss the primary missions of the KC-130J. The information will be drawn from a literature search of books, magazine articles, and other library materials relevant to the subject. Then, a static queuing theory model will be applied to the variables derived from various expert sources on aerial refueling capacity requirements and fleet sizing.

Next a simulation analysis, using the ARENA© simulation language, shall be conducted to project the relationship between the number of KC-130Js supporting an Aerial Refuel Control Point (ARCP) and the amount of time combat aircraft spend waiting to be refueled.[4] Subsequently, an EXCEL® LCC spreadsheet of the relevant costs will be developed. This spreadsheet will utilize some of the costs derived by Gates, Andersen, Kwon, and Washburn (1999) in their KC-130J LCC spreadsheet.[5]

Variability will be included in the LCC model by capturing KC-130J losses due to peace and wartime attrition. A discount rate will be embedded into the LCC model. These features will provide a more accurate depiction of the potential range of Net Present Value LCC in real (FY$2000) dollars to make the fleet sizing decisions.

Finally, cost / benefit analysis will be conducted to provide the USMC with a range of KC-130J fleet sizing options. The analysis will

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[4] Kelton, W. David, Sadowski, Randall P., Sadowski, Deborah A., *Simulation with ARENA*, McGraw Hill, 1998.

[5] Gates, William R., Young Kwon, Timothy Anderson, and Alan Washburn. Marine KC-130 Requirements Study, Naval Postgraduate School, Monterey, CA. October 1999. Section #1, pp. 6-7.

weigh the tradeoffs between fleet size, LCC and the time the USMC is willing to have combat aircraft waiting to be refueled ($\mathbf{CT_q}$) during a near simultaneous dual MTW scenario. Balancing these tradeoffs will answer the ultimate question: What KC-130J fleet size does the USMC need to adequately support USMC aerial refueling during a dual MTW.

E. ORGANIZATION

The reader now has been provided with the background, purpose, scope, and methodology for this thesis. The following chapters will flow as described in both the scope and methodology above. The study will be organized into the format depicted below.

I. Introduction
II. Static Queuing Model Methodology and Assumptions
III. Aerial Refueling Control Point Simulation Model Methodology and Assumptions
IV. LCC Model Methodology and Assumptions
V. Cost / Benefit Analysis: Alternative Fleet Sizing Options
VI. KC-130J Fleet Size, Conclusions and Recommendations

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II. STATIC QUEUING MODEL METHODOLOGY AND ASSUMPTIONS

A. INTRODUCTION

To build a model, one must understand the real world system that needs to be simulated by the computer. In this case, an Aerial Refuel Control Point (ARCP) needed to be simulated. An ARCP or the Aerial Refueling (AR) requirement comprises sixty-seven percent of the KC-130J Squadron mission in an MTW.[6] The other main missions are Direct Air Support Control (DASC), Rapid Ground Refuel (RGR), and Helicopter Refueling operations.[7] The purpose of this chapter is to describe the many variables that affect a static queuing theory model which will enable us to derive the USMC KC-130J Fleet size required for a certain theater.

This chapter is broken down into several parts, building upon each other. First, the KC-130J Aircraft schedule to support an ARCP will be described. Second, the ARCP's capacity ($K\mu$) (i.e., maximum sustainable throughput of aircraft that can be refueled per time), its interaction with the particular arrival rate (λ) used, and their combined effect on the utilization factor (ρ) shall be discussed. With the given arrival rates (λ), the capacity (μ) (maximum sustainable throughput of a single drogue), and the number of operational drogues (K) will be inputs into the queuing model equations. That will allow us to calculate the average number of aircraft waiting in the queue (INV_q) and the amount of time an aircraft spends waiting to be refueled (CT_q). Both INV_q and CT_q are crucial

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[6] Gates, William R., Young Kwon, Timothy Anderson, and Alan Washburn; Marine KC-130 Requirements Study, Naval Postgraduate School, Monterey, CA. October 1999. Section #1, p. 7.

[7] KC-130 Tactical Manual NWP 3-22.5-KC-130, Volume I, NAVAIR 01-75GAA-IT, May 1997, Department of the Navy, Office of the Chief of Naval Operations, p. 1-1.

factors in determining USMC KC-130J fleet sizing requirements. Finally, the chapter will end with a review of the important highlights. The chapter will be organized in the format depicted below:

A. Introduction
B. ARCP Schedule Explanation
C. ARCP Capacity ($K\mu$)/ Arrival rate (λ) / Utilization (ρ) Description
D. ARCP Queuing Model using Deterministic Input
E. Chapter Summary

B. AERIAL REFUEL CONTROL POINT SCHEDULE EXPLANATION

1. What is the Mission Doctrine?

The ARCP mission doctrine states that a schedule shall be established to provide tactical aerial refueling service to Fleet Marine Force (FMF) squadrons. In our case, this is a 24-hour a day aerial refueling capability during an MTW.[8] Metaphorically speaking, an ARCP is a gas station in the sky as depicted in Figure 1 below. A multi-division ARCP is depicted in Figure 1.

KC-130J Tankers are rotated through this ARCP at forty-five minute intervals over a 24-hour period to meet their refueling requirements. They must have sufficient time set aside to return to their airfield for refuel and refit. Some of these time factors include, transit time to and from the ARCP (30 to 45 minutes), and turnaround time requirements between when the tanker leaves and returns to the ARCP (3 hours and 45 minutes).[9] All of these constraints and performance

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[8] Ibid. p. 1-1.

[9] KC-130J Tanker Requirements meeting held at Naval Air Station, Patuxent River, Maryland; 24 Sep 99.

assumptions were incorporated into the 24-Hour ARCP Schedule contained in Appendix A. Portions of that schedule will be explained below.

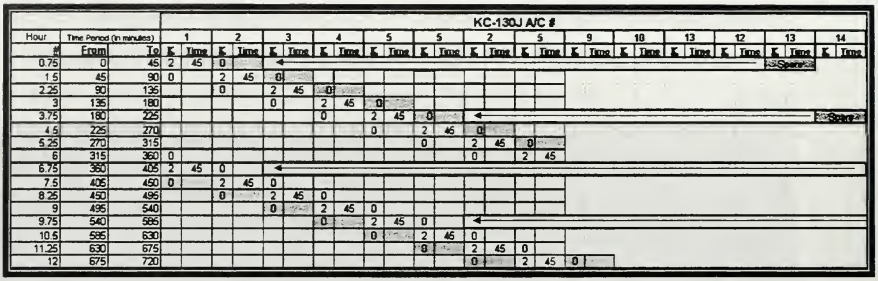
Figure 1. Photograph of an ARCP.

2. What is the Mission Schedule?

The four leftmost columns, as shown in Table 1, include the day, hour of the day, and the (from / to) time period in minutes. Under the hour of the day any number to the right of the decimal place is a percentage of the 60-minute time-period. For example, .25 hours equals fifteen minutes (15'), .5 hours equals thirty minutes (30'), and .75 hours equals forty-five minutes (45'). Also, the hour column corresponds to the right most column of the time period block.

	Hour	Time Period (in minutes)	
DAY	#	From	To
1	0.75	0	45
	1.5	45	90
	2.25	90	135
	3	135	180

Table 1. Initial Columns of the ARCP Schedule.



Hour #	Time Period (in minutes) From	To	KC-130J A/C # 1 K	Time	2 K	Time	3 K	Time	4 K	Time	5 K	Time	5 K	Time	2 K	Time	5 K	Time	9 K	Time	10 K	Time	13 K	Time	12 K	Time	13 K	Time	14 K	Time
0.75	0	45	2	45	0		◄																						Spare	
1.5	45	90	0		2	45	0																							
2.25	90	135			0		2	45	0																					
3	135	180					0		2	45	0																			
3.75	180	225							0		2	45	0		◄														Spare	
4.5	225	270									0		2	45	0															
5.25	270	315											0		2	45	0													
6	315	360	0												0		2	45												
6.75	360	405	2	45	0		◄																							
7.5	405	450	0		2	45	0																							
8.25	450	495			0		2	45	0																					
9	495	540					0		2	45	0																			
9.75	540	585							0		2	45	0		◄															
10.5	585	630									0		2	45	0															
11.25	630	675											0		2	45	0													
12	675	720													0		2	45	0											

Table 2. Snapshot of the 24-Hour ARCP Schedule.

Across the top of the schedule, as shown in Table 2, the reader will find the KC-130J number, numbered from one through sixteen. Beneath each number provides the reader with the ARCP capacity (**Kμ**) or how many drogues will be operational during a given forty-five minute period of time. An individual KC-130J can remain on station at the ARCP refueling combat aircraft from thirty minutes to an hour, the mean being forty-five minutes, which was used in this schedule.

Within the schedule, the reader will notice that from zero to forty-five minutes the first KC-130J, #1, is on station for 45 minutes. At the end of the forty-five minute period #1 is relieved by #2, which will be on-station for the next forty-five minute period, allowing #1 to return to the airfield for refuel and refit. This process is repeated for the first six hours of the mission by the first eight tankers and then is repeated again for the next six hours to make up the twelve-hour period.

Thus, a tanker is on station refueling when the number of operational drogues (**K**) column in Table 2 equals two (or two drogues) for that particular KC-130J and the time column equals forty-five minutes. When the tanker's capacity column equals zero, the tanker is either in transit to or from the ARCP, executing refuel and refit operations at the airfield, on airborne standby (spare KC-130J), or not participating in this specific twelve-hour mission.

Once another tanker relieves a tanker on station, its schedule encompasses a five hour and fifteen minute period between the time the tanker departs the ARCP and returns from the airfield to the ARCP. This period includes: forty-five minutes to return to the airfield, three hours and forty-five minutes at the airfield to refuel and refit, and another forty-five minutes to return from the airfield to the ARCP. Again, this schedule is repeated for the first eight KC-130J Tankers over the first twelve hours of the schedule and then is repeated again over the next twelve hours using tankers nine through sixteen, as shown in Appendix A.

A flight of more than two aircraft are considered a division of aircraft.[10] Thus, the schedule is broken down into three-hour periods with a four-tanker division supporting the AR requirement over that period. Further, in Table 2 a spare tanker is slated for each division of tankers. These spare tankers remain available, prepared to assume the mission for any one of the primary tankers to provide a buffer against primary tanker - mechanical breakdown or failure.

Table 3 (part of Appendix A) takes the turnaround time for all of the KC-130Js being used as spare tankers over a two-day period, deriving a mean, standard deviation, and range. The spare tanker turnaround time or the time between when it completes a twelve hour mission and it is slated as a spare tanker has a mean 6.8 hours or six hours and forty-eight minutes as shown in Table 3. The standard deviation is plus or minus 3.1 or three hours and six minutes. The range spans from forty-five minutes to twelve hours. The mean falls well within standard turnaround-time established for aircraft[11].

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[10] KC-130 Tactical Manual NWP 3-22.5-KC-130, Volume I, NAVAIR 01-75GAA-IT, May 1997, Department of the Navy, Office of the Chief of Naval Operations, p. 5-2.

[11] KC-130J Tanker Requirements meeting held at Naval Air Station, Patuxent River, Maryland; 24 Sep 99.

Spare A/C Turnaround Time		
A/C #	Hours of Turnaround Time	Time Periods
1	3.75	5
2	6	8
3	8.25	11
4	10.5	14
5	0.75	1
6	3	4
7	5.25	7
8	7.5	10
9	3.75	5
10	6	8
11	8.25	11
12	10.5	14
13	12	16
14	10.5	14
15	8.25	11
16	5.25	7
Mean	**6.8**	9.1
StdDev	**3.1**	4.1
Range	**0.75 to 12**	

Table 3. Spare KC-130J Tanker Turnaround Time.

In summary, Appendix A indicates that it will take sixteen KC-130J Tankers to support one ARCP. However, what is the ARCP capacity (**Kμ**), or how many combat aircraft can the ARCP refuel per period of time? The next section shall answer that question.

C. AERIAL REFUEL CONTROL POINT CAPACITY / ARRIVAL RATE / UTILIZATION DESCRIPTION

1. What is the Capacity of an Aerial Refuel Control Point?

It is important to point out here that refuel (process) time, or the time it takes an aircraft to be refueled by the ARCP, is an assumption made to better define the model. However, this assumption was recently validated at a KC-130J Requirements meeting.[12] See assumption number

[12] Ibid.

one of Figure 2 at the end of this chapter; further, the other assumptions made to formulate this model will be explained in the following chapters.

A combat aircraft is refueled on average t_s units of time. As stated above, one drogue can refuel **one** combat aircraft in five minutes (t_s = 5') on average. Thus, we denote capacity (μ) as **1 / t_s** (see Equation 1), where μ measures the maximum sustainable throughput of aircraft that need to be refueled, per unit of time.[13] As shown in the first row of Table 4, one drogue on a KC-130J can refuel one aircraft every five minutes or twelve per hour.

Combining the capacity of two drogues constitutes a single KC-130J supporting an ARCP, the capacity of the ARCP (as shown in Equation 2 and row two of Table 4) is 0.40 aircraft per minute or (60' **X** 0.40) twenty-four per hour. By adding another division to support the ARCP, its capacity jumps to 0.80 aircraft per minute, or forty-eight per hour, as shown in rows three and four of Table 4. Notice that as one adds a division to the ARCP, the aircraft per minute raises by 0.40 or twenty-four per hour. Thus, as divisions are added to support the AR requirement, the ARCP capacity ($K\mu$) increases significantly (see Equation 2).

Refuel Division Capacity (without Drogue Failure)							
# of Divisions	# of A/C	Drogues	t_s	Drogue Capacity (μ)	ARCP Capacity	Per Hour	*Process Time*
0	0	1	5	0.20	-	12.0	5
1	16	2	-		0.40	24.0	
2	32	4	-		0.80	48.0	
3	48	6	-		1.20	72.0	

Table 4. Refuel Division Capacity (without Drogue Failure).

[13] Adleman, Dan, Barnes-Schuster, Dawn, and Eisenstein, Don; *Operations Quadrangle: Business Process Fundamentals*, The University of Chicago Graduate School of Business, 1999, p. 39.

Capacity (μ) = 1 / t_s

*where t_s = the amount of time it takes to refuel **one** aircraft

Equation 1. Capacity (μ) Equation

ARCP Capacity = K(μ)

*where **K** = is the number of drogues (channels) operational and μ is the capacity (μ) of a single drogue

Equation 2. ARCP Capacity Equation

2. Why does the Arrival rate at the Aerial Refuel Control Point matter?

In order to answer that question, we must know what constitutes an arrival rate. Combat aircraft arrive at the ARCP on average once every t_a time units. This is called the inter-arrival time.[14] For example, **one** aircraft can arrive every 1.7094 minutes (t_a = 1.7094'), as shown in the second column of Table 5. By dividing one by the inter-arrival time, we derive the arrival rate at the ARCP. Thus, the arrival rate (λ) equals one divided by the inter-arrival time or $\lambda = 1/t_a$ (see equation 3).[15]

Table 5 provides data derived from Operation DESERT STORM arrival rates.[16] The first column denotes the scenario; in this case, it reflects the DESERT STORM high and medium rates. In the peak period (CNA-HIGH) during Operation DESERT STORM, aircraft were arriving to be refueled at an arrival rate of 0.5850 per minute, or approximately thirty-five per hour. During a medium intensity period (CNA-MED), the

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[14] Ibid. p. 39.

[15] Ibid. p. 39.

[16] Cox, Gregory, USN/USMC Tanking Requirements, Center for Naval Analysis, May 95, p. 7.

arrival rate was 0.3383 per minute, or approximately twenty per hour, as shown in column 4 of Table 5.

Arrival Rates (λ) per Theater			
Theater	t_a	(λ) Arrival Rate	λ per hour
DESERT STORM (CNA-HIGH)	1.709402	0.5850	35.1
DESERT STORM (CNA-MED)	2.955665	0.3383	20.3

Table 5. Arrival Rates per Theater.

$$\lambda = 1 / t_a$$

*Where t_a = the inter-arrival time between aircraft arrivals

Equation 3. Arrival Rate Equation

Having described capacity (μ), ARCP capacity (**K**μ), and arrival rates (λ), it is important to discuss how they interact. Their interaction is captured in the form of utilization (ρ). Utilization (ρ) is arrival rate (λ) divided by ARCP capacity or the number of channels (**K**) times capacity per channel (μ); $\rho = \lambda / K\mu$ (see Equation 4)[17]. Utilization (ρ) is always less than one ($\rho < 1$).

$$\rho = \lambda / K\mu$$

Equation 4. Utilization Factor Equation

As ρ gets closer to one, the aircraft queue waiting to be refueled would grow until the entire population of USMC fixed wing (FW) aircraft are in one of three places. The aircraft needing to be refueled will be either waiting to be refueled, being refueled, or just departing the ARCP. This occurs because the ARCP is refueling an infinite population of FW

[17] Anderson, David R., Sweeney, Dennis J., and Williams, Thomas A.; *An Introduction to Management Science, 8th Edition*, West Publishing Company, 1997, p. 506.

aircraft. However, the waiting line would increase indefinitely at some point (depending on the system) as ρ gets closer to one[18].

An infinitely increasing queue does not realistically simulate the real world ARCP procedures. Further, Marine planners will always ensure there is enough ARCP capacity ($K\mu$) to meet the requirements (λ). Thus, ARCP capacity must always be greater than the arrival rate ($K\mu > \lambda$) and utilization (ρ) can never be greater than one.

The closer utilization (ρ) is to one the higher your ARCP utilization and the less time your ARCP spends idle or not refueling any aircraft. However, a tradeoff must be made because as ρ approaches one, there will be a larger queue of aircraft waiting at the ARCP (INV_q) and the aircraft will wait longer to be refueled (CT_q).

3. What Utilization (ρ) is achieved by the Aerial Refuel Control Point given the Arrival Rate (λ) driving the ARCP Capacity ($K\mu$) Requirement?

Combining Tables 4 and 5 determines how many divisions of KC-130Js are needed to provide sufficient capacity to service the aircraft as they arrive. Table 6 shows the tanker utilization factor (ρ), in the shaded portion of Table 6, given the two DESERT STORM arrival rates, and the number of divisions required to service each particular arrival rate.

DESERT STORM (CNA-HIGH), with an arrival rate (λ) of 0.5850, requires at least two divisions or four drogues with an ARCP capacity ($K\mu$) of 0.80 to service the arriving aircraft without an infinitely increasing queue. Using two divisions in this scenario prevents utilization from peaking above one, which is necessary to meet planning requirements.

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[18] Ibid. p. 506.

Arrival Rates (λ) per Theater						
Theater	t_a	(λ) Arrival Rate	λ per hour	Util (ρ)	# of Divisions	
DESERT STORM (CNA-HIGH)	1.7094	0.5850	35.1	**73.1%**	2	
DESERT STORM (CNA-MED)	2.9557	0.3383	20.3	**84.6%**	1	
DESERT STORM (CNA-MED)	2.9557	0.3383	20.3	**42.3%**	2	

Refuel Division Capacity (without Drogue Failure)							
# of Divisions	**# of A/C**	**Drogues (K)**	t_s	**Drogue Capacity (μ)**	**ARCP Capacity (Kμ)**	**Per Hour**	***Process Time***
0	0	1	5	0.20	-	12.0	5
1	16	2	-		0.40	24.0	
2	32	4	-		0.80	48.0	

Table 6. Deriving Utilization (ρ).

Two divisions implies a utilization factor of 73.1%, as shown in Table 6 above. The utilization factor (ρ) reflects the probability that an arriving aircraft will have to wait because the ARCP is busy.[19] This factor also implies that the ARCP is busy seventy three percent (73%) of the time; twenty-seven percent (27%) of the time the KC-130Js on station at the ARCP are idle. In effect, there is twenty-seven percent excess capacity.[20] Both of the interpretations will become fruitful in later discussions.

The same interpretations can be attributed to the DESERT STORM (CNA-MED) arrival rate ($\lambda = 0.3383$). This is less than the ARCP capacity ($K\mu = 0.40$) of a single division ARCP. A single division gives us an 84.6% utilization factor that can be interpreted as described above. Next, we analyze how the arrival rate (λ), capacity (μ), and number of drogues (**K**) interact when used as input factors into queuing equations.

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[19] Adleman, Dan, Barnes-Schuster, Dawn, and Eisenstein, Don; *Operations Quadrangle: Business Process Fundamentals*, The University of Chicago Graduate School of Business, 1999, p. 39.

[20] Kelton, W. David, Sadowski, Randall P., Sadowski, Deborah A., *Simulation with ARENA*, McGraw Hill, 1998, p. 22.

D. AERIAL REFUEL CONTROL POINT QUEUING THEORY MODEL USING DETERMINISTIC INPUT

When used as deterministic inputs to queuing theory equations, arrival rate and capacity, coupled with **K**, can help calculate certain pertinent performance indicators, which aid in the fleet sizing problem. Two such pertinent figures include the average number of aircraft waiting to be refueled (a.k.a. Queue Size or $\mathbf{INV_q}$) and the time an aircraft spends waiting to be refueled (a.k.a. Cycle Time of the queue or $\mathbf{CT_q}$)[21].

Deterministic inputs mean that the inputs are known and do not vary; therefore, this queuing model possesses deterministic averages containing the variability given them by the queuing theory equations. However, these equations are more static and do not utilize the variability of a simulation model. Nevertheless, they provide a solid starting point.

We now know from the Marine KC-130 Requirements Study, that an aircraft should rarely wait five minutes to be refueled and never wait ten minutes.[22] Using this constraint, we can derive the values for $\mathbf{INV_q}$ and $\mathbf{CT_q}$. These values determine how many divisions of KC-130Js are needed to support an ARCP, given the projected arrival rate.

We begin by introducing $\mathbf{P_0}$, or the probability that there will be no units in the system. Equation 5 provides this equation.[23] Column six of table 8 contains the already computed values of $\mathbf{P_0}$ as well as the computed values of the other equations needed to understand the queuing theory

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[21] Adleman, Dan, Barnes-Schuster, Dawn, and Eisenstein, Don; *Operations Quadrangle: Business Process Fundamentals*, The University of Chicago Graduate School of Business, 1999, p. 39.

[22] Gates, William R., Young Kwon, Timothy Anderson, and Alan Washburn. Marine KC-130 Requirements Study, Naval Postgraduate School, Monterey, CA. October 1999. Section #2, p. 24.

[23] Anderson, David R., Sweeney, Dennis J., and Williams, Thomas A.; *An Introduction to Management Science, 8th Edition*, West Publishing Company, 1997, p. 505.

model used. The equations are presented to aid the reader should he or she desire a deeper understanding.

$$P_0 = \frac{1}{\sum_{n=0}^{K-1} \frac{(\lambda/\mu)^K \lambda\mu}{n!} + \frac{(\lambda/\mu)^K}{K!}\left(\frac{K\mu}{K\mu - \lambda}\right)}$$

* Thus **n** begins with zero and extends to the number derived by **K** minus 1 in the summation, depending on the number of Drogues (**K**) are in use.

Equation 5. P_0 Equation[24]

What queuing theory equations are used to derive numbers for $\mathbf{INV_q}$ and $\mathbf{CT_q}$? We must start by using an M / M / S queue. The first and second **M** stand for (Markov) Poisson inter-arrival rates and (Markov) Exponential service times, respectively. The **S** stands for the number of servers used, which equates to the number of channels, in our case a KC-130J with two drogues. The $\mathbf{INV_q}$ and $\mathbf{CT_q}$ equations are given by Equations 6 and 7, respectively.

$$\mathbf{INVq\ (M / M / S)} = \frac{(\lambda/\mu)^K \lambda\mu}{(K-1)!\,(K\mu - \lambda)} P_0$$

Equation 6. Queue Size

$$\mathbf{CT_q\ (M / M / S)} = \frac{\mathbf{INVq}}{\lambda}$$

Equation 7. Cycle Time of the Queue

The Exponential service times are assumed when using the M / M / S queuing equations as stated in Figure 2, at the end of the chapter. The

[24] The term n!, factorial is defined as n! = n (n-1)(n-2)...(2)(1). For example, 3! = (3)(2)(1) = 6. A special rule exists where n = 0, 0! = 1! by definition.

ARCP service time may or may not be exponential; however, the data is currently unavailable to validate that assumption. Thus, in order to use the static queuing theory model and later the simulation model the ARCP exponential service time is assumed.

The Poisson probability distribution used for the arrival rate (λ) in our queuing equation defines the probability distribution of arrivals occurring over a specific period; the exponential probability distribution models the time between arrivals. Both distributions are commonly used in Queuing Theory Models.[25] The Poisson and the exponential distributions are mirrors of one another, metaphorically speaking of course. For example, column two marked $\mathbf{t_a}$ in Table 7 below, depicts time between arrivals, an exponential distribution; one aircraft will arrive every 1.7094 minutes. That same number can be converted into a Poisson distribution (60' / 1.7094 = 35 per hour) to derive 35.1 arrivals per hour, as in the last column of table 7.

Arrival Rates (λ) per Theater			
Theater	t_a	(λ) Arrival Rate	λ per hour
DESERT STORM (CNA-HIGH)	1.709402	0.5850	35.1
DESERT STORM (CNA-MED)	2.955665	0.3383	20.3

Table 7. Poisson / Exponential Probability distribution example

By plugging the information provided in Table 6, concerning arrival rates (λ), capacity (μ), and the number of drogues (**K**), into the queuing theory equations above, one can derive the number of KC-130J divisions necessary to support the projected arrival rate. The result is given in Table 8 below. USMC will need two divisions of KC-130Js to meet the CNA-HIGH arrival rate (λ) given in table 6. For reference, Table 6 is

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[25] Kelton, W. David, Sadowski, Randall P., Sadowski, Deborah A., *Simulation with ARENA*, McGraw Hill, 1998, p. 22-23.

reproduced within Table 8. The last column of table 8 provides the number of KC-130Js required to support each Theater's FW aircraft refueling requirement. So, thirty-two KC-130J Tankers will be required in the CNA-HIGH Theater to stay below the targeted five-minute wait time constraint. All of the static queuing calculation schedules are contained in Appendix B, which reflects the numerous queuing tables discussed in this and later chapters.

Using a single division of KC-130Js in the CNA-MED Theater does not meet the five-minute average wait requirement. Thus, we need to add a division of KC-130Js to get below the wait time constraint. However, making that significant jump in capacity by adding another sixteen KC-130Js, drastically reduces $\mathbf{INV_q}$ and $\mathbf{CT_q}$. Using one division, the arrival rate (λ) = 0.3383 and ARCP capacity ($\mathbf{K\mu}$) = .40 provides a utilization factor (ρ) of 84.6%; which does not provide much excess capacity (15.4%). However, increasing capacity ($\mathbf{K\mu}$) to .80, decreases ρ to 42.3%, giving an excess capacity of 57.7%. This implies a smooth throughput, avoiding the long waiting lines ($\mathbf{INV_q}$) and congestion ($\mathbf{CT_q}$) observed using a single division of KC-130Js to support the ARCP requirement.

E. CHAPTER SUMMARY

In deriving the proper size of the USMC KC-130J Tanker fleet, trade-offs will have to be made between wait time and cost as one can observe in the CNA-MED Theater. These tradeoffs will be handled further in Chapter V. However, this chapter described how the basic multiple channel (server), Queuing Theory Model works. More specifically, how the given arrival rate (λ) plus the available ARCP capacity ($\mathbf{K\mu}$) drive the utilization factor (ρ), the number of aircraft waiting in the queue ($\mathbf{INV_q}$), and waiting time to be refueled ($\mathbf{CT_q}$). Finally, the reader should review the assumptions made in this model up to this point summarized in Figure 2 below.

KC-130J Requirements - STATIC Queuing Model

Categories							Number of Divisions				KC-130Js
							1		2		#
Theater	λ per hour	λ (rate) per minute	μ per hour	μ (rate) per minute	P_0	# of Drogues (Channels)	CT_q (min)	INV_q	CT_q (Min)	INV_q	Refueling
DESERT STORM (CNA-HIGH)	35.1	0.585	12	0.20	0.0422	4			2.225	1.302	32
DESERT STORM (CNA-MED)	20.3	0.338	12	0.20	0.0835	2	12.57	4.25	-	-	16
DESERT STORM (CNA-MED)	20.3	0.338	12	0.20	0.1811	4			0.232	0.078	32

Arrival Rates (λ) per Theater

Theater	t_a	(λ) Arrival Rate	λ per hour	Util (ρ)	# of Divisions
DESERT STORM (CNA-HIGH)	1.709	0.585	35.1	**73.1%**	2
DESERT STORM (CNA-MED)	2.956	0.338	20.3	**84.5%**	1
DESERT STORM (CNA-MED)	2.956	0.338	20.3	**42.3%**	2

Refuel Division Capacity (without Drogue Failure)

# of Divisions	# of A/C	Drogues (K)	t_s	Drogue Capacity (μ)	ARCP Capacity (Kμ)	Per Hour	*Process Time*
0	0	1	5	0.20	-	12.0	5
1	16	2	-		0.40	24.0	
2	32	4	-		0.80	48.0	

Table 8. KC-130J Requirements – STATIC Queuing Theory Model

The next chapter shows how a simple ARENA simulation model can be developed to validate the static Queuing Theory Model presented here. Consequently, we shall observe how our static queuing model can be used to validate a more complex ARENA simulation model containing the KC-130J division schedule explained at the beginning of this chapter. Potentially, this can provide us with an interesting range of answers to the USMC fleet sizing question.

ARCP MODEL ASSUMPTIONS MADE:

1. Average refueling (process) time for a single arriving aircraft = 5 minutes (8 minutes at night).

   (This includes the time it takes an aircraft to approach, achieve probe / drogue hookup, and receive the average amount of fuel)

2. Arrival Rates (λ) (inter-arrival times) and refueling (service) times follow an exponential distribution.
3. The population of aircraft needing to be refueled is infinite.

Figure 2. ARCP Model Assumptions

III. AERIAL REFUELING CONTROL POINT SIMULATION MODEL METHODOLOGY AND ASSUMPTIONS

A. INTRODUCTION

The last chapter described a schedule for an Aerial Refuel Control Point (ARCP) and that schedule captured a crucial element: the ARCP's capacity ($K\mu$). Then it discussed how a given arrival rate (λ), coupled with the ARCP's capacity ($K\mu$), provided the utilization factor (ρ). This utilization factor (ρ) ascertains how busy the ARCP is, given the particular λ. Further, we used these factors as inputs into a static queuing model. This model estimates the number of aircraft waiting in the queue (INV_q) and the arriving aircraft's waiting time to be refueled (CT_q). However, this is a static queuing theory model. What can better reflect the variability that an ARCP encounters in the real world?

A simulation model can emulate the assumptions mentioned in Chapter II (see Figure 2) and apply a statistical distribution to the refueling (process) time. This imbues our model with same variability that an ARCP may realistically encounter. This chapter will introduce a simple simulation model using the ARENA simulation program. The outputs closely parallel those of the static queuing model. This serves to validate the static model developed in Chapter II, but consistency between models also allows the static queuing model to validate the simulation model. Finally, we will enhance the simulation model to better emulate the schedule described in Chapter II and contained in Appendix A.

The chapter will be organized in the format depicted below:

A. Introduction

B. ARCP Simple Simulation Model Description and Output

C. ARCP Enhanced Simulation Model Description and Output

D. Chapter Summary

B. AERIAL REFUEL CONTROL POINT SIMPLE SIMULATION MODEL DESCRIPTION AND OUTPUT

1. How is the Simulation Model similar to the Static Queuing Theory Model?

A simulation model uses mathematical expressions and logical relationships to model real system behavior.[26] Simply, the Static Queuing Theory Model described in Chapter II "simulates" the steady-state of the ARCP refueling sequence using predetermined distributions for λ and μ to obtain solutions for $\mathbf{INV_q}$ and $\mathbf{CT_q}$. A simulation model uses the selected statistical distribution to specify possible values for arrival rate (λ) and capacity (μ) which determine the outcome for both $\mathbf{INV_q}$ and $\mathbf{CT_q}$. A simulation model can do this over thousands of iterations. Again, the outputs from the separate models can be used to cross validate each model with the other.

For example, a simulation model can mimic an ARCP supporting a MTW over a thirty-day period, as is done here. It applies the unique statistical distribution to a given input, in our case arrival rate (λ) and capacity (μ), and solves for $\mathbf{INV_q}$ and $\mathbf{CT_q}$ each time an aircraft arrives and flows through the ARCP. By doing this, the ARENA program that

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[26] Anderson, David R., Sweeney, Dennis J., and Williams, Thomas A.; *An Introduction to Management Science, 8th Edition*, West Publishing Company, 1997, p. 535.

supports the simulation model can gather an average for $\mathbf{INV_q}$ and $\mathbf{CT_q}$ over that thirty-day period. The results can help the analyst make policy decisions, such as the KC-130J fleet sizing question.

This simulation model is not meant to provide the optimal solution to a given question.[27] However, it can help policy makers make cogent decisions using variables like $\mathbf{INV_q}$ and $\mathbf{CT_q}$. For example, decision-makers can estimate how many KC-130Js the ARCP will require to hold the $\mathbf{INV_q}$ low and keep the $\mathbf{CT_q}$ below five minutes. Thus, a simulation model aids in understanding how a system (ARCP) realistically behaves allowing policy makers to establish sound operating policies and make informed decisions to achieve the desired system outcome. In our case, this involves making the correct decision regarding the USMC KC-130J fleet size.

2. How does a Simulation Model differ from a static queuing model?

To answer this question, we must begin by developing a simple simulation model in ARENA© involving a multi-channel server. Figure 3 provides an overview of the simulation model. We can use this simulation model to derive all of the pertinent information gleaned from the static queuing model. Notice that the upper left-hand corner of Figure 3 contains information on AIRCRAFT RECEIVING FUEL, to include the number waiting to be refueled ($\mathbf{INV_q}$) and the time in the queue ($\mathbf{CT_q}$). The right bottom corner contains KC-130J Division Utilization (ρ) output.

The real difference between this simple simulation model and the static queuing theory model lies in the fact that a simulation model can emulate the variability encountered in real life. For example, the mean refuel (process) time for one drogue on a KC-130J is five minutes, exponentially distributed; five minutes is the mean service time. The

simulation generates random exponential variates around that mean of five minutes. Every aircraft that arrives will be refueled with a mean time of five minutes, but individual aircraft will be refueled in more or less time than five minutes. This better simulates the variability that the ARCP realistically encounters during an MTW.

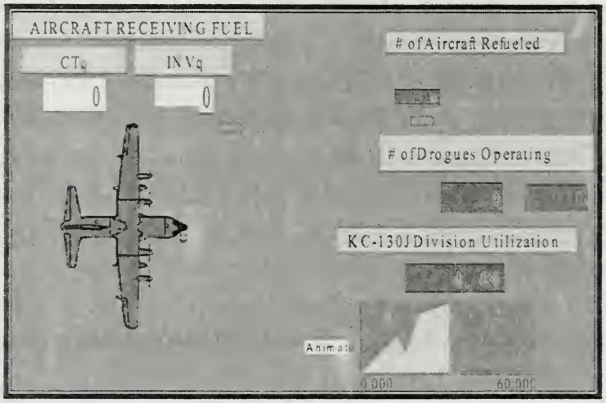

Figure 3. Simple Simulation Overview

Essentially, the ARENA simulation language uses a mathematical algorithm to decide which number to use from the exponential distribution for the refueling (process) time when each aircraft arrives to be refueled. An appropriate analogy would depict a computer with a set of dice with all of the potential numeric possibilities from an exponential distribution with a mean of five minutes. As an aircraft arrives the computer rolls the dice (runs the algorithm) to decide how long it will take to refuel the aircraft. This allows a simulation to effectively model what occurs in the real system. Refueling (process) time ($\mathbf{t_s}$) or capacity (μ) and the ARCP's total capacity ($\mathbf{K}\mu$) are not static deterministic numbers but variates over the range depicted by the distribution chosen.

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[27] Ibid. p. 535.

The exact same process is used to determine when an aircraft will arrive to receive fuel. As explained in the last chapter, an exponential distribution (time between arrivals) is equivalent to a Poisson distribution (number of arrivals over a period of time).[28] Since we run this simulation over a varying time period, we want to choose the continuous statistical equivalent to a (finite) Poisson distribution; thus, we selected an Exponential distribution in ARENA to depict the inter-arrival time. Thus, the inter-arrival time (t_a) varies around the mean depending on the number chosen by the algorithm (roll of our fictitious computer dice).

The variates derived by the computer for inter-arrival times (t_a) and refuel (process) time (t_s) ultimately drive the variability of the arrival rate (λ) and the refuel (process) time (μ) for the ARCP. Thus, enabling the simulation model to solve the equations outlined in Chapter II, among others, for each aircraft that flows through the ARCP. By doing this, the simulation model can collect the average numbers for $\mathbf{INV_q}$ and $\mathbf{CT_q}$ over the simulation period. A simulated thirty-day period or longer, can provide the analyst with a better understanding of what $\mathbf{INV_q}$ and $\mathbf{CT_q}$ will be for a given ARCP size in a MTW. This shall allow us to realistically model ARCP behavior in MTW scenario.

The logic blocks of the simulation program are simple. Figure 4 below visually depicts the simulation logic. First, we begin with the particular arrival rate used. The first simulation run, uses an exponential (time between arrivals) arrival rate (λ) with a mean of 1.7094. This implies that 0.585 of an aircraft arrives per minute or 35.1 aircraft per hour, the CNA-HIGH rate (refer to Table 9 below under Arrival Rates per Theater). The incoming aircraft will either be immediately refueled or enter the queue.

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[28] Ibid. p. 504.

Next, the aircraft enters the Refuel Division portion of the ARCP, depicted by the Enter, Process, and Leave blocks in figure 4. These blocks merely guide the arriving aircraft (entity) to the KC-130J currently on station for the Refuel Division. Once the aircraft completes the probe / drogue hookup and begins refueling, it receives fuel using an exponentially distributed refuel (process) time with a mean of five minutes. As soon as the aircraft has completed refueling, it detaches from the drogue and departs the ARCP.

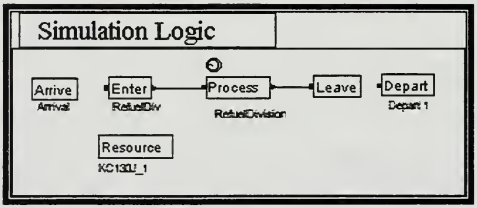


Figure 4. ARENA Simulation Logic

The KC-130J icon the reader sees in Figure 3 simulates a single aircraft on station with two or four drogues (channels) operational. This is intended to show the reader the base or simple simulation model; later models add levels of sophistication to better depict the behavior of an actual ARCP. This basic model simply introduces the simulation concept and allows the simulation model results to cross-validate both the simulation and static queuing models.

3. How does the output from the simulation model for INV_q and CT_q compare to the output from the static queuing theory output?

Table 9 below replicates Table 8 from Chapter II and also in Appendix B; it is presented here to compare the output from the static queuing and simulation models. Simulation results are presented in Figure 5 below. The top portion of Figure 5 visually depicts a box and

whisker diagram showing the mean value for both $\mathbf{INV_q}$ and $\mathbf{CT_q}$ as well as a ninety-five percent confidence interval around that mean. The ninety-five (**95%**) percent confidence interval means that we have a **95%** confidence that both the true mean of the number of aircraft waiting in the queue ($\mathbf{INV_q}$) and of the time the aircraft spend in the queue ($\mathbf{CT_q}$) will fall within the range depicted by the diagram.

KC-130J Requirements - STATIC Queuing Model

Categories							Number of Divisions				KC-130Js
							1		2		#
Theater	λ per hour	λ (rate) per minute	μ per hour	μ (rate) per minute	P_0	# of Drogues (Channels)	CT_q (min)	INV_q	CT_q (Min)	INV_q	Refueling
DESERT STORM (CNA-HIGH)	35.1	0.585	12	0.20	0.0422	4			2.225	1.302	32
DESERT STORM (CNA-MED)	20.3	0.338	12	0.20	0.0835	2	12.57	4.25	-	-	16
DESERT STORM (CNA-MED)	20.3	0.338	12	0.20	0.1811	4			0.232	0.078	32

Arrival Rates (λ) per Theater					
Theater	t_a	(λ) Arrival Rate	λ per hour	Util (ρ)	# of Divisions
DESERT STORM (CNA-HIGH)	1.709	0.585	35.1	73.1%	2
DESERT STORM (CNA-MED)	2.956	0.338	20.3	84.6%	1
DESERT STORM (CNA-MED)	2.956	0.338	20.3	42.3%	2

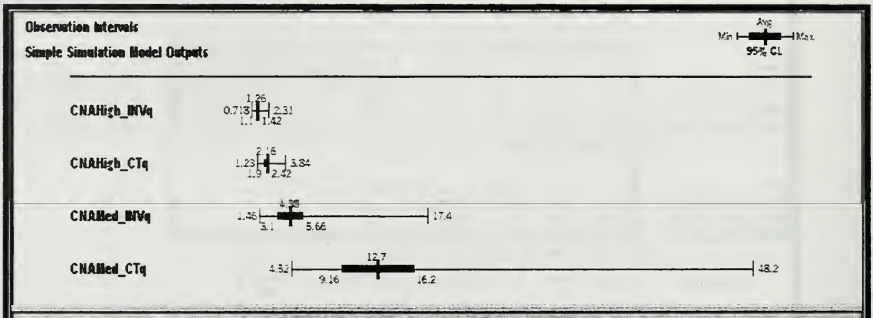
Refuel Division Capacity (without Drogue Failure)							
# of Divisions	# of A/C	Drogues (K)	t_s	Drogue Capacity (μ)	ARCP Capacity (Kμ)	Per Hour	Process Time
0	0	1	5	0.20	-	12.0	5
1	16	2	-		0.40	24.0	
2	32	4	-		0.80	48.0	

Table 9. Static Queuing Model Results

Notice that values of the static queuing results for $\mathbf{INV_q}$ (1.302) and the $\mathbf{CT_q}$ (2.225) lie well within the **95%** confidence interval of the simulation output in Figure 5 below. Thus, the simulation model validates that static queuing model. Further, all of the values the simple simulation model derived for $\mathbf{INV_q}$ and $\mathbf{CT_q}$ lie within one to three percentage points of the static queuing theory model outputs, which fall well within acceptable simulation validation parameters[29]. We can infer that the static queuing model validates the simulation model. Therefore, each model cross-validates the other.

[29] Simulation validation parameters dictate that the values derived from the simulation model must be within 10% of the static queuing model values.

What exactly do the simulation results imply? We have a **95%** level of confidence that the true average (mean) number of aircraft waiting to be refueled ($\mathbf{INV_q}$) will be between 1.1 and 1.42. We can also be **97.5%** confident that the true average (mean) amount of time an aircraft spends waiting in the queue ($\mathbf{CT_q}$) will not exceed 2.42 minutes. In addition, we possess a **95%** confidence level that the true average time an aircraft spends waiting, on any given day, will be between 1.9 and 2.42 minutes.[30]



Classical C.I. Intervals Summary
Simple Simulation Model Outputs

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
CNAHigh_INVq	1.26	0.431	0.161	0.718	2.31	30
CNAHigh_CTq	2.16	0.702	0.262	1.23	3.84	30
CNAMed_INVq	4.38	3.43	1.28	1.46	17.4	30
CNAMed_CTq	12.7	9.39	3.51	4.52	48.2	30
CNAHighl_Util	0.727	0.0341	0.0127	0.672	0.788	30
CNAMedl_Util	0.849	0.058	0.0217	0.74	0.944	30

Figure 5. Simple Simulation Model Outputs for $\mathbf{INV_q}$ and $\mathbf{CT_q}$

Before moving to the next section, it is useful to briefly discuss utilization (ρ). In the last chapter, we stated that ρ could be interpreted as the amount of time the ARCP was busy. The last two lines of the simulation model output above show the utilization figures for CNA-

[30] Berenson, Mark L., Levine, David M., and Stephan, David; *Statistics for Managers using Microsoft® EXCEL*, Prentice Hall, New Jersey, 1998, p. 294 -295.

HIGH and CNA-MED. Average utilization is listed in the first column. We can interpret these numbers to mean that all of the ARCP's drogues are busy 72.7% of the time with a CNA-HIGH arrival rate (λ); they are busy 84.9% of the time for CNA-MED.

These two numbers are both within one percent of the static queuing model (ρ) numbers contained in Table 9 above. These lie well within acceptable validation parameters for each model, as discussed earlier. These (ρ) values will become relevant as we enhance our simulation model in the next section of this chapter.

Considering the range of the potential possibilities, the simulation model better emulates the variability an ARCP realistically encounters. Therein lies the critical difference between the simulation model and the static queuing theory model. The simulation generates many variates that are used to solve equations for $\mathbf{INV_q}$ and $\mathbf{CT_q}$ for many different aircraft allowing for the gathering of data over a simulated period of time. Nevertheless, the information gained from both models has enabled us to cross-validate both models. Next, we will add an additional level of sophistication to the simulation model.

C. AERIAL REFUEL CONTROL POINT ENHANCED SIMULATION MODEL DESCRIPTION AND OUTPUT

1. How do we enhance the existing simulation model?

Appendix A contains the schedule of the 24-Hour ARCP Schedule. In our simple simulation model, we have one KC-130J with two or four drogues on station continually, depending on the number of KC-130J Divisions supporting the ARCP. What information could we derive from the simulation model by mimicking the ARCP Schedule to enhance our simulation model? First, we would need to add three more KC-130J

Tankers, which are simply servers or resources in ARENA©, under the Enter, Process, and Leave logic, as shown below in Figure 6.

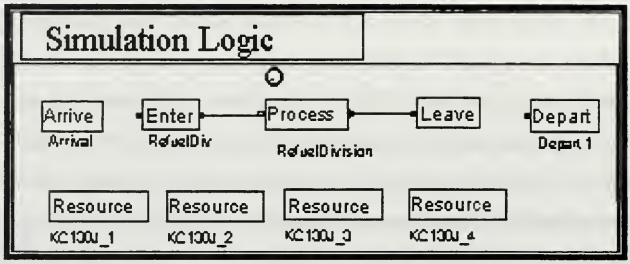


Figure 6. Enhanced Simulation Logic

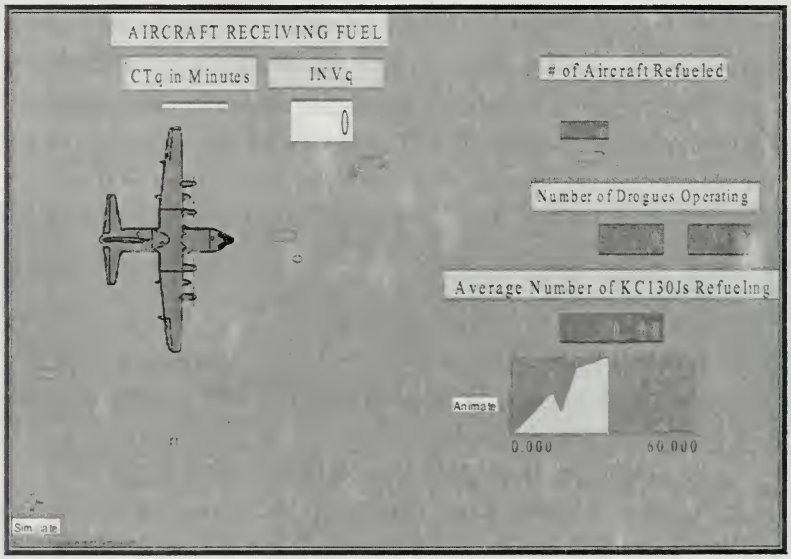


Figure 7. Enhanced Simulation Overview

By doing so, our simulation model depicts the three additional KC-130J Tankers that will support the ARCP, as shown in Figure 7. These four aircraft simulate the sixteen aircraft that are required to support one ARCP during a MTW. Further, if we need to increase ARCP capacity ($K\mu$) because the theater arrival rate (λ) is greater than the ARCP

capacity ($\lambda > K\mu$), then each KC-130J icon can represent two or three KC-130Js supporting two or three Refuel Divisions, respectively.

Given these enhancements, we can compare the enhanced simulation output to the simple (base) simulation model and the basic queuing theory model. Figure 8 below, contains the enhanced simulation model output. Next we shall explore how and why the two models differ?

2. How and why do the simulation outputs differ between the two models?

We have used four KC-130Js (resources) to simulate the sixteen KC-130J schedule shown in Appendix A. The total number of KC-130Js supporting the ARCP is divisible by four. Instead of making the simulation exceedingly complicated, we simply used four KC-130Js to depict the eight KC-130Js supporting the first twelve hour period, and another four supporting the last twelve hour period of the twenty-four hour day. Thus, four KC-130Js in the simulation depict sixteen KC-130Js supporting a twenty-four hour ARCP schedule (see Appendix A). For reference, a snapshot of this schedule is provided in table 10.

The first KC-130J in the simulation does not directly correspond to the first in the schedule, it is merely a placeholder in the simulation. Depending on the part of the schedule being simulated at any given time, it could represent the first, fifth, ninth, or thirteenth KC-130J depicted in the schedule, depending on the time frame being simulated by the model.

The results of the Enhanced Simulation Model are depicted in Figure 8. By comparing the output from the different simulation or static models, as shown in this chapter, some interesting results appear. It is immediately obvious that there is a significant difference in the $\mathbf{INV_q}$ and $\mathbf{CT_q}$ numbers contained in Table 9 and Figure 5 and those depicted in Figure 8. This section asks what is the difference and why does it exist? The difference lies in scheduling KC-130J aircraft to support the ARCP.

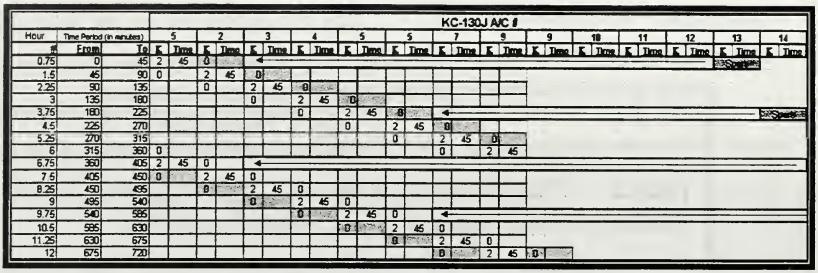


Table 10. Snapshot of the 24 Hour ARCP Schedule

Once an ARCP is established, a KC-130J arrives every forty-five minutes to relieve the KC-130J on station. The relieved KC-130J returns to the airfield to undergo refuel and refit operations, as both discussed in Chapter II and depicted in Table 10. During that transition period, there are two KC-130Js on station, refer to Table 10. KC-130J (#1), that support the ARCP during the preceding forty-five minute period, will not depart the ARCP and return to the airfield until it completes refueling any aircraft in the refueling process (drogue hookup, refueling, probe detaching). During that albeit short transition period, the ARCP capacity ($K\mu$) effectively doubles.

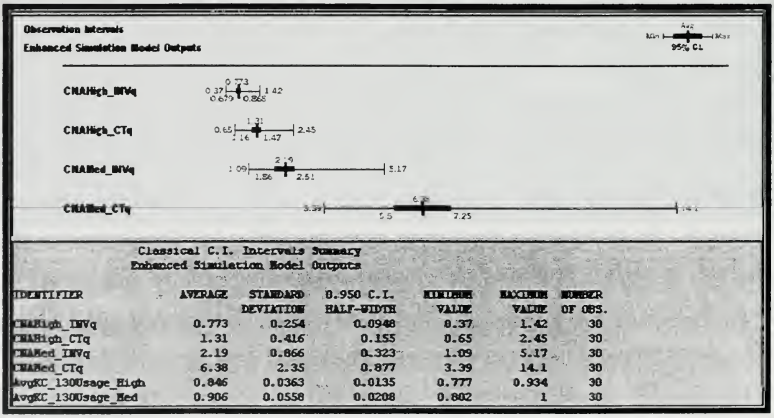


Figure 8. Enhanced Simulation Model Outputs

The probability that the KC-130J on station will be busy when the relief KC-130J arrives for CNA-HIGH arrival rate (λ) is 72.7%, the utilization factor (ρ) (refer to Figure 5 for the simple simulation ρ factor). Remember we are using two divisions of KC-130Js to support that (λ) or AR requirement for the CNA-HIGH theater, refer to either Table 9 or Figure 5. Thus, during 72.7% of the transition periods, or approximately twelve times per day for the CNA-HIGH arrival rate (λ), the ARCP capacity ($K\mu$) doubles for a short period until the KC-130J on station can complete refueling those aircraft actually in the process prior to its departure.

Comparing the numbers for $\mathbf{INV_q}$ and $\mathbf{CT_q}$ between the simple and the enhanced simulation model, the overlap between sorties causes approximately a forty-percent reduction ([1.26 - .773] / 1.26 = .3865 ~ 40%) in $\mathbf{INV_q}$ and $\mathbf{CT_q}$ for CNA-HIGH theater. The difference for CNA-MED Theater is somewhat different. Comparing $\mathbf{INV_q}$ and $\mathbf{CT_q}$ between the simple and enhanced simulation model, implies a difference of approximately fifty-percent ([4.38 – 2.19] / 4.38 = .50 ~ 50%).

The difference can be best explained by using the utilization (ρ) factors in Table 9. Two KC-130J Tanker divisions are supporting CNA-HIGH, with four drogues on station at any one time (as depicted in Figure 9 below), and two drogues in the case of CNA-MED. This provides a ARCP utilization (ρ) factor of 73.1% (Table 9), for CNA-HIGH and 84.6% for CNA-MED.

Thus, CNA-HIGH has **26.9%** excess capacity that can absorb aircraft in the $\mathbf{INV_q}$, CNA-MED only has **15.4%** excess capacity. Therefore, during the transition period (spike in $K\mu$), CNA-HIGH is likely to have aircraft in the refueling queue. The added capacity can help clear out $\mathbf{INV_q}$ more quickly, because on average more drogues are available, thereby reducing the $\mathbf{CT_q}$. The ARCP supporting CNA-MED does not possess as much excess capacity and on average less drogues are

available. Thus, it will have a more difficult time clearing out the $\mathbf{INV_q}$ causing the difference between the two simulation model outputs to be greater for CNA-MED then for CNA-HIGH when compared to the static queuing outputs.

Therefore, the spike in $\mathbf{K\mu}$ occurring during the transition periods over a thirty-day period causes between a forty and fifty-percent reduction in $\mathbf{INV_q}$ and $\mathbf{CT_q}$, depending on the current utilization (ρ) of the ARCP. This brings out yet another reason why a simulation model better depicts the behavior of a real ARCP supporting the AR requirement during a MTW. Simply using the static queuing theory model would not have uncovered this relevant fact of ARCP behavior.

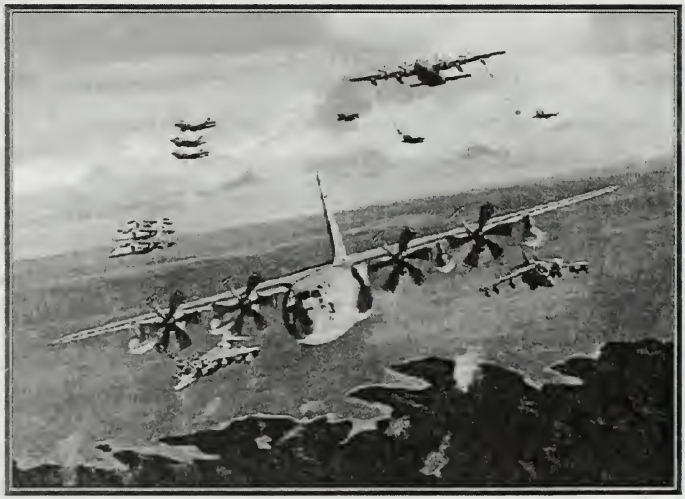


Figure 9. Visual depiction of a two division ARCP.

3. How does the Enhanced Simulation Model depict Utilization (ρ)?

The last two rows of the data, identified by **AvgKC_130Usage_ High** or **Med** in the shaded portion of Figure 8, represent the average

number of KC-130s being used over the thirty day simulation period. This factor is similar to utilization (ρ), but it is not the same.

Since we used four KC-130Js (servers) to simulate the ARCP schedule in the Enhanced Simulation Model, we cannot gather utilization information on a single KC-130J (server) on station all the time, as we did in the simple simulation model and the static queuing model. Instead, we had four KC-130Js, in the enhanced simulation model, that are being utilized approximately 25% of the time. Consider the other 75% of the time, which accounts for the KC-130J in transit to or from the airfield, or at the airfield being prepared to return to the ARCP. We also have spikes in ARCP capacity ($\mathbf{K\mu}$). These facts combined together make it difficult to ascertain an ARCP utilization factor (ρ).

To estimate how much the ARCP was being used, we simply summed the utilization factors capture by ARENA© for each KC-130J (resource). This estimates the average number of KC-130Js supporting the ARCP. However, we cannot call this utilization (ρ) because ρ is never greater than one ($\rho < 1$); with four KC-130Js, this factor frequently peaks above one, depending on the λ used.[31] However, we can use this number to indicate if the theater arrival rate (λ) is stressing the ARCP system.

For example, observe the ARCP ρ, in Figure 5, identified by **CNA_Med1_Util** in the shaded area; this figure indicates that the ARCP ρ is approximately 84.9%. This causes both the high $\mathbf{INV_q}$ and $\mathbf{CT_q}$ to exceed the five-minute constraint. This indicates that we must increase our $\mathbf{K\mu}$ to bring $\mathbf{CT_q}$ down to an acceptable level. Now look at the Enhanced Simulation Model Output, specifically **AVGKC_130Usage_ Med** within the shaded area of Figure 8. Notice that its average runs

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[31] Adleman, Dan, Barnes-Schuster, Dawn, and Eisenstein, Don; *Operations Quadrangle: Business Process Fundamentals*, The University of Chicago Graduate School of Business, 1999, p. 39.

around 90.6%, indicating we must increase $K\mu$ as above. Even though the Enhanced Simulation Model Output does not give us ρ, it indicates the same decisions: in this case add another Refuel Division to support the ARCP in the CNA-MED Theater.

4. How can we enhance this simulation model further to better depict how an ARCP would operate supporting a Major Theater War?

One more aspect of the ARCP should be modeled to ensure that the Enhanced Simulation Model adequately reflects the behavior and variability of an ARCP supporting a MTW: drogue failures. Drogue failures include any occurrence that may cause the KC-130J on station to loose the use of a drogue and incur a reduction in ARCP capacity ($K\mu$). Examples include, but are not restricted to, hydraulic, pump, or mechanical failure, or even an inexperienced pilot damaging the drogue through improper probe / drogue coupling procedures.

Fortunately, these occurrences are statistically rare, occurring on average .025 (or 2.5%) of the time.[32] However, it is appropriate to add this sophistication (drogue failure) to the simulation.[33] Figure 10 below, provides a visual depiction of the logic surrounding the generation of drogue failures.

Every forty-five minute period in the simulation model, a drogue failure is created; this failure enters the chance block (i.e.; the second block from the left). There the computer rolls a pair of dice, metaphorically speaking, with all of the numerical possibilities between zero and one. Every forty-five minutes the computer rolls the dice to

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[32] Interview with Major Patrick S. Flanery, USMC, Marine Aviation Weapons and Tactics Squadron One (MAWTS-1) KC-130 Instructor, 28 Jul 99.

[33] KC-130J Tanker Requirements meeting held at Naval Air Station, Patuxent River, Maryland; 24 Sep 99.

decide if a drogue failure occurs. If the computer's dice generate a number less than or equal to .025, a failure will occur; if the number generated is greater than .025, a failure will not occur. But, how does this affect the enhanced simulation model outputs?

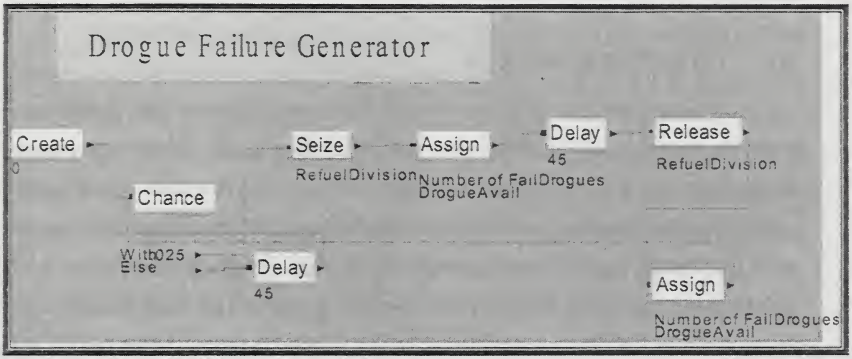

Figure 10. Drogue Failure Generator

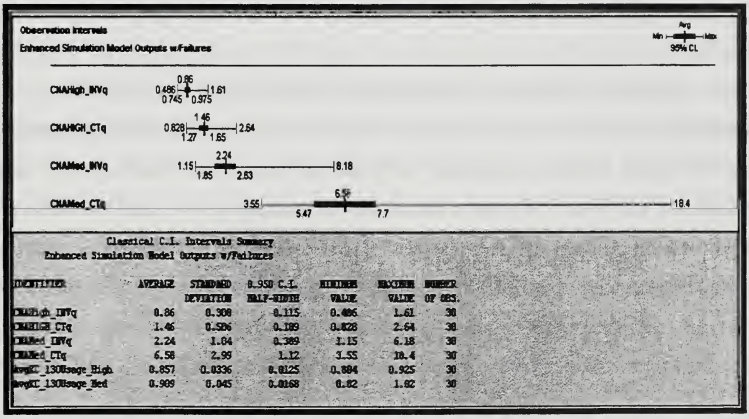

Figure 11. Enhanced Simulation Model Outputs w/Failures

Figure 11 shows the Enhanced Simulation Outputs with drogue failures. As one might expect, the $\mathbf{INV_q}$, $\mathbf{CT_q}$ and the average number of KC-130Js being used will increase from two to ten percent in both the

CNA-HIGH and CNA-MED cases. This is within validation tolerances discussed earlier. This modification, while not significantly affecting the results, enables us to add another level of sophistication to the enhanced simulation model to better replicate real world ARCP operations to estimate the AR requirements in a MTW.

D. CHAPTER SUMMARY

As discussed in detail in this chapter, a simulation model can provide superior insights into the real life behavior of the system being studied, in our case an ARCP. In some cases, as in the case of utilization (ρ), it cannot provide us with the exact information provided by the static queuing model or the simple simulation model. Nevertheless, the information gathered by modeling the real world ARCP will prove invaluable in helping us develop a range of possible KC-130J Tanker fleet sizing solutions. A better understanding of how the ARCP functions during a MTW will help ferret out the most logical range of fleet sizing solutions.

The next chapter will describe the Life Cycle Cost (LCC) spreadsheet model for the KC-130J fleet. The analysis will use costs derived from the cost study completed by Gates, Andersen, Kwon, and Washburn (1999).[34] By the end of the next chapter we shall be able to ascribe a cost figure to a particular KC-130J fleet size that will enable us to begin our Cost /Benefit Analysis, chapter five.

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[34] Gates, William R., Young Kwon, Timothy Anderson, and Alan Washburn; Marine KC-130 Requirements Study, Naval Postgraduate School, Monterey, CA. October 1999. Section #1, p. 7.

IV. LIFE CYCLE COST MODEL METHODOLOGY AND ASSUMPTIONS

A. INTRODUCTION

To ascribe a cost figure to the fleet size, previously determined by the simulation model, requires capturing the cost attributed to procuring, operating, and maintaining a KC-130J. Professor Alan Washburn of the Operations Research Department at the Naval Postgraduate School (NPS) contributed to a Marine KC-130 Requirements study. He captured several of the crucial KC-130J cost factors, including procurement, operations, and maintenance (O&M) costs.[35] Using these non-inflated real cost figures as inputs to a Life Cycle Cost (LCC) spreadsheet determines a total cost figure, in real dollars, of a particular fleet size.

This chapter will be broken up into several distinct sections describing the LCC model. First, the Sensitivity Analysis sheet will be described to indicate how variation in key variables affect the overall cost of a given fleet size. Second, the Deployment and Attrition sheet will be discussed showing how net fleet size and age is affected by the variables input into the Sensitivity Analysis sheet. Thirdly, the cost schedule sheet will be reviewed to explain all of the interactions between the pertinent variables contained within the LCC model. Next, we discuss how another simulation program can be added to imbue our LCC model with the cost variability seen in the real world. Finally, the outputs from the charts' sheet will be discussed to describe the charts reflecting the input variables from the Sensitivity Analysis sheet. Appendix C contains all of the

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[35] Gates, William R., Young Kwon, Timothy Anderson, and Alan Washburn; Marine KC-130 Requirements Study, Naval Postgraduate School, Monterey, CA. October 1999. Section #1, p. 7.

schedules presented in this chapter as tables. The chapter outline is as follows:

A. Introduction
B. Sensitivity Analysis Sheet
C. Deployment and Attrition Sheet
D. Cost Schedule Sheet
E. Simulation Inputs and Affects
F. Chart Outputs Sheet
G. Chapter Summary

B. SENSITIVITY ANALYSIS SHEET

1. Why is deriving a Procurement Schedule so critical to the development of the Life Cycle Cost Model?

The factors which should be considered when conducting a cost Sensitivity Analysis for procuring a major system are listed in the first three lines of table 11; Number of KC-130Js Procured; Number of KC-130Js per year; Years in Procurement Plan. By deriving the maximum number of KC-130Js to be procured in any given year, the analyst can develop a procurement schedule. In this case, the KC-130J Program Manager provided this information. Lieutenant Colonel Isleib, USMC stated that, at most, the USMC would procure an average of six KC-130Js per year.[36]

The fleet size is entered into the first line of Table 11, entitled "number of KC-130Js procured." The number procured is divided by the next line "number of KC-130Js [procured] per year." This results in the third line, the "years in the procurement plan." These variables are

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[36] Telephone interview with LtCol Isleib, USMC; Program Manager, KC-130J; 19 July 99.

critical because they establish the procurement plan based on the total number of KC-130Js purchased and the number procured per year.

The procurement plan is a major cost driver in the total LCC of the KC-130J fleet. At fifty six million ($56.1 million) per KC-130J, entered in line four of Table 11, procurement costs add up quickly. Fifty-six million dollars is the flyaway cost to purchase a single KC-130J.[37] Further, a KC-130J is assumed to undergo a Service Life Extension Program (SLEP) after fifteen years of service. The SLEP cost an estimated five million dollars, as shown on line five of table 11.[38]

Information used in Sensitivity Analysis		
Number of KC-130Js Procured		36
Number of KC-130Js per year		6
Years in Procurement Plan		5
Cost per KC-130J	$	56.1
SLEP Costs	$	5.0
% of Cost Growth at 15 years		2%
Discount Rate		2.9%
Probability of a MTW		12%
Attrit w/		5%
Attrit w/out		0.01%
Expected KC-130J Life Cycle		40 Years

Table 11. Information used in Sensitivity Analysis

2. Why are cost growth and discount rate important to the Life Cycle Cost Model?

To make our Life Cycle Cost Model accurate, we must identify costs that will grow over time, and then discount them back to their present value. O&M cost growth will be discussed first. Then, we will

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[37] Gates, William R., Young Kwon, Timothy Anderson, and Alan Washburn; Marine KC-130 Requirements Study, Naval Postgraduate School, Monterey, CA. October 1999. Section #1, p. 6.

[38] Ibid. Section 1, p. 6.

describe the discount rate used to appropriately discount the total fleet cost figure to today's dollars.

Line six of table 11 provides a cost growth percentage (2%) for the KC-130J beginning in the fifteenth year of service. According to the NPS Marine KC-130 Requirements study, one point eight million ($1.886M) of the O&M total costs ($2.294M) will begin to "creep" or inflate by two percent (2%) after a KC-130J has been in service for fifteen years. The rest of the Total O&M costs ($.408M) does not creep.[39] These costs are shown in Table 12 below, which is also included on the Sensitivity Analysis sheet of the LCC Model (Appendix C).

O&M Costs per KC-130J (X 10^6)		
Static Costs		0.408
Non-static Costs (creep)		1.886
Total O&M Cost in FY$99 (Constant)		2.294

Table 12. O&M Costs per KC-130J

The line marked Discount Rate in table 11 depicts the projected real discount rate as delineated in the Office of Management and Budget's Circular No A-94.[40] This discount rate is used to discount real (constant year dollar) cost flows in fiscal year (FY) 2000 dollars. When we discuss the net present value cost of the KC-130J fleet it will be depicted in FY2000 constant (non-inflated) dollars. This will provide the Marine reader with an accurate portrayal of the costs of the KC-130J fleet in today's dollars.

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[39] Ibid. Section 1, p. 7-8.

[40] Office of Management and Budget; Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs; United States Government, 29 October 1992, p. 19.

3. Why would the probability of an MTW, potential attrition rates, and the service life of a KC-130J affect the Life Cycle Cost Model?

The probability of an MTW, and the attrition factor account for the number of KC-130Js lost during that MTW, can affect the KC-130J Fleet LCC. Further, an attrition factor should be estimated for KC-130J Fleet losses during normal peacetime operations. These factors will be discussed below.

The line immediately below the discount rate is the probability that an MTW occurs in any given year. This probability was derived from discussion with Ambassador Rodney Minot of the National Security Affairs Department NPS.[41] A twelve-percent probability may seem rather high; however, this variable can be changed to reveal its affect on the LCC of the KC-130J fleet, if considered appropriate.

Finally, the last three lines of Table 11 portray the percentage of KC130J losses occurring during an MTW (5%), the percentage of KC-130J losses occurring during normal peacetime operations (.01%), and the expected KC-130J Life Cycle (40 years). Certainly, some losses may occur during an MTW and some do occur during peacetime operations.

These factors interact to affect the KC-130J Fleet LCC. For example, if the probability of an MTW increases, one would incur a higher LCC to replace the additional KC-130Js lost during the conflict. The attrition factor for normal peacetime operations will also effect the KC-130J Fleet LCC, but not significantly at its projected value.

The final line of table 11 contains the service life of a KC-130J. The forty-year service life of a KC-130J is estimated from empirical knowledge of the service life for the current KC-130F/R fleet. There are

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[41] Interview with Ambassador Rodney Minot, 28 September 99.

also O&M Difference and Variability schedules on the sensitivity analysis sheet; each will be explained later in this chapter.

After discussing those factors unique to the sensitivity analysis sheet (Appendix C), let's look at how they interact with the deployment and attrition sheet (Appendix C).

C. DEPLOYMENT AND ATTRITION SHEET

The deployment and attrition sheet contains without attrition and with attrition blocks. An attrition block was added to account for KC-130Js lost in an MTW. This increases the number of KC-130Js procured and reduces the number of KC-130Js in operation in a given year. Finally, the last column depicts the phase-out of the KC-130J fleet, as the fleet reaches the end of its useful life cycle beginning in the fortieth year.

Deployment / PhaseOut Plan								
KC-130J Aerial Refueler								
	without Attrition		with Attrition					
Year	Fielding Plan	Procurement Inv.	MTW	Attrition	KC130Js Losses	Procurement w/Attrit	KC130Js in Ops	PhaseOut Plan
1997	-	-	0	0.00%	-	2	-	-
1998	2	2	0	0.00%	-	3	2	-
1999	3	5	0	0.00%	-	2	5	-
2000	2	7	1	5.00%	-	6	7	-
2001	6	13	1	5.00%	1	7	12	-
2002	6	19	0	0.01%	-	6	19	-
2003	6	25	0	0.01%	-	6	25	-
2004	6	31	1	5.00%	2	8	29	-
2005	5	36	0	0.01%	-	5	36	-
2006	-	36	0	0.01%	-	-	36	-

Table 13. Snapshot of the KC-130J Deployment / Phaseout Schedule

1. Why do we need to maintain accountability of the number of KC-130Js fielded and the number in the procurement inventory?

It is critical to maintain accountability of our KC-130J inventory net of attrition. We must always know how many KC-130Js we need to meet the requirement discussed in Chapters II and III. For example, the

total number of KC130Js procured in line 1, Table 11, matches the number of KC-130Js in table 13 in 2005 – 2006, after completing the initial procurement process. Procurement numbers for years 1997 through 2000 represent actual numbers established prior to the beginning of this study.

One final point regarding the without attrition block. Observe that five (5) procurement years past 2000 are included in Table 13. This corresponds to the year's (5) in the procurement plan in table 11. This can be used as an important validation tool and provides the required flexibility to change the fleet size, as appropriate, to meet the requirements identified in the simulation model. This will be explored further in the next chapter.

2. How does the attrition block make the model more realistic?

By employing an attrition block, we can model real world events that may affect the total LCC of the KC-130J fleet. The main event that could affect the total LCC would be an MTW. How can we model the affect of an MTW?

This thesis uses the same principles described in the simulation model in Chapter IV. The random number generator in the EXCEL© spreadsheet program, along with the probability on the sensitivity analysis sheet (12%) determines whether an MTW occurs or not. We again use the computer's fictitious set of dice that contain all of the numerical possibilities between zero and one, to decide whether we will have an MTW.

Each time F9 is pressed on the computer keyboard, the computer rolls the dice. Within this LCC spreadsheet model, one can watch the estimated costs change by merely pressing F9 on the keyboard. If the number rolled by our fictitious dice is 0.12 or less, an MTW will occur.

If the number derived is greater that 0.12, or twelve-percent, an MTW will not occur.

Notice that MTW (column #4) and Attrition (column #5) correlate with one another. If there is an MTW, attrition is 5%; without an MTW, attrition stays at 0.01%. Again, the attrition percentages are drawn from the sensitivity sheet outlined above. Further, when an MTW is predicted KC-130J losses are depicted in column #6.

With attrition, more KC-130Js need to be procured in the year of the MTW, as shown by procurement w/attrition (column #7). Observe that the procurement schedule (column #7) is one year ahead of KC-130Js in operation (column #8). The aircraft procured in any given year, for the purposes of this model, do not enter operations until the following year.

Finally, the last column of Table 13 is the Deployment / PhaseOut Schedule. This column contains the KC-130J fleet phase out plan. The phase out plan reflects the procurement plan forty years later, except that the USMC divests itself of KC-130Js. In other words, the USMC fielded two KC-130Js in 1998; thus, forty-years later, in 2037, those two KC-130Js will be retired and phased out of service. In the next section, we will describe how the LCC schedule captures this information and allows us to attribute a LCC to a particular fleet size.

D. COST SCHEDULE SHEET

Table 14 below is a snapshot of the LCC schedule contained in Appendix C. The first column is the year of the LCC; the range of different categories is spread across the second row. Each category will be described in sufficient detail to provide a basic understanding of the model.

1. Why would the accountability of a particular fiscal year designator be important to the Life Cycle Cost Model.

The year designator (column #2) indicates the number of years in the program from fiscal year (FY) 2000. The years before FY2000 are identified by the number of years that separates them from FY2000. This column is used in the net present value (discounting) calculations. As we calculate the Net Present Value (Costs) of a particular KC-130J fleet size, we must use the future value equation (equation 8 below) for those years preceding FY2000. After FY2000, we must bring each year's costs back to FY2000 (constant) dollars (equation 9 below). This is critical to deriving an accurate cost estimate for the LCC of the particular KC-130J fleet size in FY2000 dollars. When we begin discussing Costs (FY2000$) this discussion will become more relevant.

2. How are the costs accounted for in the Life Cycle Cost Model?

The columns in Table 14 that depict Procurement with attrition and KC-130Js in operation (columns #3 and #4) are the same as those with the same headings in table 13. Recall that the KC-130J we procure (pay for) this year will not be in operations (fielded) until next year. Thus, they will not incur O&M costs until the following year. Further, the cost of KC-130Js (column #5) multiplies the number of aircraft procured that year, after accounting for attrition, by the cost to procure the aircraft ($56.1 million), as shown in the sensitivity analysis schedule. The Static and Non-static O&M cost categories without creeping (columns #6 and #7) can be calculated in the similar way. By using the static and non-static O&M cost figures contained in table 12 (page 44, above) and multiplying them by the number of KC-130Js in operation.

Cost growth (column #8) delineates the costs associated with the two percent "creep" as a KC-130J reaches its fifteenth year of service.

This model portrays the newest KC-130Js (having not reached 15 years of service) being attrited first. By loosing newer KC-130Js, the two-percent creep of KC-130Js is not postponed for another fifteen years; thus, the two-percent creep will be incurred from the fifteenth year until retirement.

Life Cycle Cost Analysis:					KC-130J Fleet NPV (LCC)				$ 4,809,549,396	
Year / Category	Year Designator	Procurement w/ attrition	LC-130Js in Operation	Cost of KC-130J	Static Costs	Non-Static Costs	Cost Growth (Lose New)	SLEP Costs	Costs (FY2000)	Cumulative (FY2000) Costs
1997	3	2	0	112.2	-	-	-	-	122.2	122.2
1998	2	3	2	168.3	0.816	3.772	-	-	183.1	305.3
1999	1	2	8	112.2	2.040	9.430	-	-	127.3	432.6
2000	3	6	7	336.6	2.856	13.202	-	-	352.7	785.2
2001	1	6	19	336.6	5.304	24.518	-	-	368.1	1,141.3
2002	7	2	19	336.6	7.752	35.834	-	-	389.1	1,500.4
2003	3	6	35	336.6	10.200	47.150	-	-	361.6	1,861.9
2004	7	2	31	336.6	12.648	58.466	-	-	363.7	2,225.6
2005	5	2	36	280.5	14.688	67.896	-	-	314.7	2,540.3
2006	5	2	36	0.0	14.688	67.896	-	-	69.6	2,609.9
2007	7	2	36	0.0	14.688	67.896	-	-	67.6	2,677.5
2008	8	0	36	0.0	14.688	67.896	-	-	65.7	2,743.2
2009	3	2	36	0.0	14.688	67.896	-	-	63.6	2,807.1
2010	10	2	34	112.2	13.872	64.124	-	-	142.9	2,950.9
2011	11	0	36	0.0	14.688	67.896	-	-	60.3	3,010.3
2012	12	0	36	0.0	14.688	64.049	3.847	10.000	65.7	3,076.0

Table 14. Snapshot of the Life Cycle Cost Analysis

By doing this we build an LCC model that accounts for the highest O&M costs because we do not defer the creeping cost affect for fifteen years each time we loose a KC-130J. This was necessary to avoid undue complications in the LCC model. Certainly, there is some probability that the USMC will lose both older and newer KC-130Js during an MTW; however, that calculation lies beyond the scope of this thesis.

To estimate the range of costs between losing new verses old KC-130Js in an MTW, another sheet, LCC (2), and attrition schedule has been developed. LCC (2) is the same as LCC except for the cost growth column. The cost growth column in LCC (2) assures the USMC loses older KC-130Js during an MTW. This was done to furnish a scaling between the two extremes; Table 15 below depicts the numerical differences. Thus, in this case the difference between losing new verses

old is about one hundred and eighty-nine million dollars. This represents approximately four percent of the cost of losing new KC-130Js during an MTW.

O&M Difference Schedule	
Cost Lose Newer	$ 4,809,549,396
Cost Lose Older	$ 4,619,770,144
Difference btwn losing old / new	$ 189,779,253
% Difference of old	3.95%

Table 15. O&M Difference Schedule

Finally, the second to the last column in Table 14 sums columns four through eight and calculates the total annual costs in FY2000 (constant) dollars. The LCC model uses either equation 8 (future value) or 9 (present value) below depending of the year being considered. Those years prior to FY2000 will use the future value equation (equation #8) to calculate costs for those years in FY2000 dollars; years following FY2000 will use the present value equation to bring each year's costs back to FY2000 dollars.

$$\text{Future Value} = C_n \times (1 + d)^n$$

*Where C_n = cost incurred at the end of time period n.

d = Appropriate discount rate for the future cash flows

n = Time period when the cost occurs

Equation 8. Future Value Equation[42]

The last column calculates a cumulative total of the FY2000 dollar costs for the KC-130J fleet, from the initial procurement until the last KC-130J is phased out. The cumulative cost in this column measures the final KC-130J Fleet Net Present Value (NPV) in any given year; the final year is the overall cost of the program in FY2000 dollars. The next

[42] Blanchard, Benjamin S.; *Logistics Engineering and Management, 5th Edition*, Prentice Hall Publishing, Upper Saddle River, New Jersey; 1998, p. 490.

section explores how to make the LCC model more accurately reflect the variability in LCC over the service life of our KC-130J Fleet.

$$\text{Present Value} = C_n \mathbf{X} (1 + d)^{-n}$$

*Where **Cn** = cost incurred at the end of time period n.
d = Appropriate discount rate for the future cash flows
n = Time period when the cost occur

Equation 9. Present Value Equation[43]

E. SIMULATION INPUTS AND AFFECTS

By using an EXCEL© spreadsheet - add on, called Crystal Ball©, we can imbue the LCC Model with some realistic cost variability. The factors that seem to possess the most significant uncertainty are SLEP costs, % Cost Growth [in O&M Costs], discount rate, probability of an MTW, and the attrition the KC-130J fleet would incur during an MTW. These factors feed through the sensitivity analysis sheet and ultimately affect the entire model to provide us with a NPV (Costs) of the fleet size chosen.

Table 16 shows the distribution (column #5) around the mean or average (column #2) value for each of the variables explored by Crystal Ball©. The distribution is characterized by the parameters contained in change and variability (columns #3 - #4). For example, the SLEP costs use a normal distribution with a mean of five million and a standard deviation of five hundred thousand. Alternatively, the probability of an MTW assumes a triangular distribution with a mean of twelve percent, a lower bound of five percent, and an upper bound of fourteen percent. A visual depiction of the distributions for each of the Key External or Policy variables shown in Table 16 is contained in Appendix D.

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[43] Maher, Michael; *Cost Accounting: Creating Value for Management*, McGraw-Hill Companies, Inc.; 1997, p. 700.

Variability Chart				
Key External & Policy Variables	Mean	Change	Variability	Distribution
SLEP Costs	$ 5.0	$ 0.50	σ = +/- .5	Normal
% of Cost Growth at 15 years	2%	1%	σ = +/- 1%	Normal
Discount Rate	2.9%	1%	σ = +/- 1%	Normal
Probability of a MTW	12%		from 5% to 14%	Triangular
Attrit w/	5%	2%	σ = +/- 2%	Normal

Table 16. Variability Chart

Again, the computer has the set of dice with all of the numeric values possible in the defined distribution. As the simulation model runs, the computer rolls the dice over many trials (iterations). With each trial, the value we are attempting to forecast is derived, in this case the KC-130J Fleet NPV (LCC). Over numerous trials, a range of forecasted values for NPV (LCC) will begin to develop. With sufficient trials, this enables us to forecast the NPV (LCC) of a particular KC-130J fleet size with a certain level of confidence (similar to the ARCP simulation). This is illustrated in Figure 12.

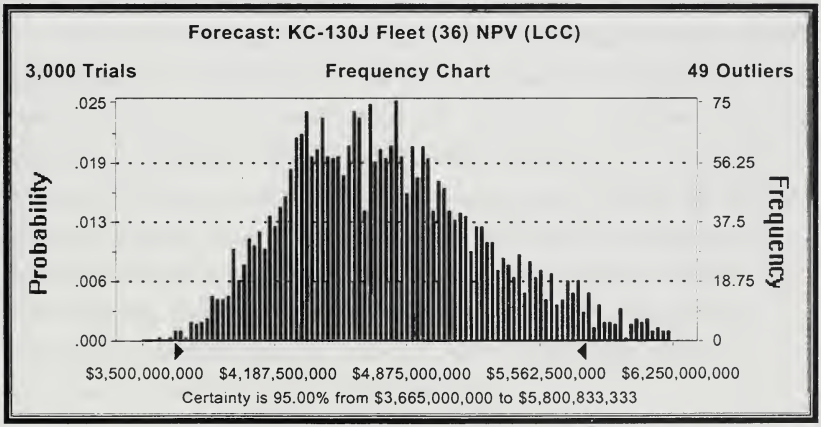

Figure 12. Forecast: KC-130J Fleet NPV (LCC)

We now have a 95% confidence that a fleet size of thirty-six KC-130Js will cost between 3.7 and 5.8 billion in FY2000 dollars, as depicted

in the last line of Figure 12. This provides a cost range coupled with a level of confidence that the cost of a specified KC-130J fleet size will fall within those parameters. The overall Project NPV (FY$2000 Costs) is detailed visually in the chart sheet.

F. CHART OUTPUTS SHEET

The chart sheet provides two visual depictions that help the reader understand where the dollars are spent on the KC-130J fleet. Figure 13 breaks down the Life Cycle Costs of the KC-130J fleet into procurement, O&M, and SLEP Costs. O&M costs make up the majority (56%) of the LCC for the KC-130J Fleet. This is consistant with most LCC projections.[44]

Figure 14 portrays the annual costs of the KC-130J fleet over the entire life cycle. The peaks and valleys reflect the probabilistic MTW during the KC-130J Life Cycle. Costs increase as the USMC replaces KC-130Js lost in an MTW. Again, this graph is consistent with other LCC projections.[45]

[44] Ibid. p. 180.

[45] Ibid. p. 180.

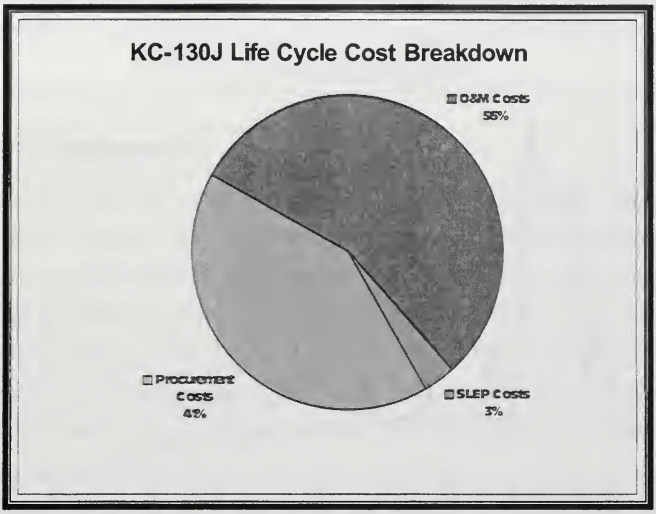

Figure 13. KC-130J Life Cycle Cost Breakdown

G. CHAPTER SUMMARY

We have developed a simple LCC Model that contains some realistic cost variability. This model will allow us to attach a cost figure [KC-130J Fleet NPV (LCC)] to a particular KC-130J fleet size. Ultimately, this will enable us to conduct a Cost / Benefit Analysis (Chapter V). This will combine fleet size, system performance figures derived from the ARENA© Simulation Model reviewed in Chapter III, and the LCC values for the fleet size estimated using the LCC model. Combining these outputs will enable Marine planners to consider a range of KC-130J fleet sizing possibilities, highlighting the tradeoffs between fleet size, system performance, (waiting time ~ $\mathbf{CT_q}$), and LCC.

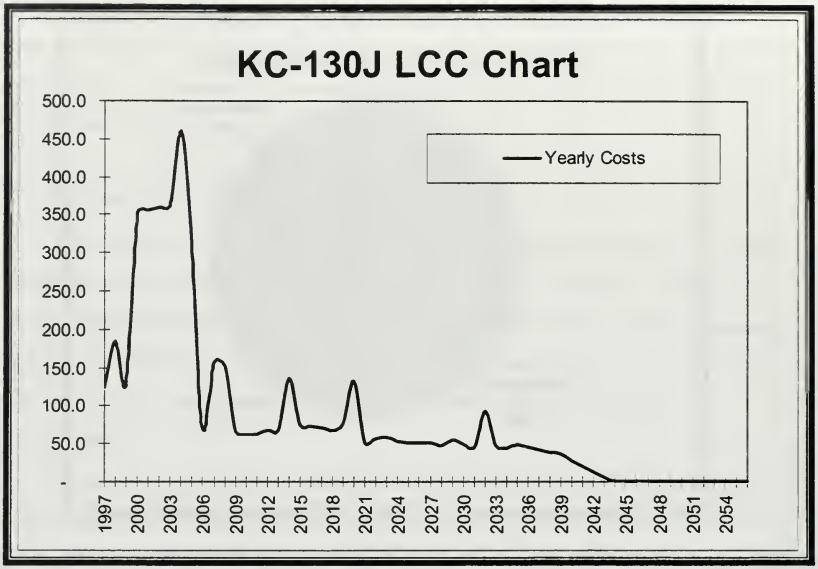

Figure 14. KC-130J LCC (Graph) Chart

V. COST / BENEFIT ANALYSIS: ALTERNATIVE FLEET SIZING OPTIONS

A. INTRODUCTION

In the operations plans for two near simultaneous MTWs, the critical point occurs when the USMC transitions its aviation assets from one theater (western MTW) to the other (eastern MTW). This is when USMC aerial refueling assets (KC-130Js) are most taxed.[46] This particular transition point drives the USMC KC-130J fleet size. Thus, capturing the requirement for USMC aerial refueling assets at that point provides the most accurate picture of the required USMC KC-130J fleet size.

This chapter identifies the fleet size required to meet the aerial refueling requirements for each MTW during both day and night ARCP operations using the enhanced simulation model outlined in Chapter III. Using the LCC Model, a KC-130J Fleet NPV (LCC) figure will be defined. Finally, a cost / benefit analysis will be conducted to highlight the tradeoffs between $\mathbf{CT_q}$ and LCC of the particular KC-130J Fleet size.

The chapter outline is as follows.

A. Introduction

B. KC-130J Fleet Sizing Requirements for day operations

C. KC-130J Fleet Sizing Requirements for night operations

D. KC-130J Fleet Sizing Costs

E. KC-130J Fleet Sizing Cost / Benefit Analysis

F. Chapter Summary

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[46] Gates, William R., Young Kwon, Timothy Anderson, and Alan Washburn; Marine KC-130 Requirements Study, Naval Postgraduate School, Monterey, CA. October 1999. Section #2, p. 24.

B. KC-130J FLEET SIZING REQUIREMENTS FOR DAY OPERATIONS

We can use the queuing theory spreadsheet from chapter II to define the preliminary requirement for KC-130J divisions to meet the dual MTW requirement. Table 17 (Appendix B) provides the starting point for the simulation model. Also, recall that our daytime refuel (process) time for one drogue is five minutes.

Notice that the arrival rate per hour (λ) for East Surge (column #2) is the same as the CNA-HIGH scenarios used in chapter II and III. Thus, East Surge (MTW) requires two divisions of KC-130Js; anything less would cause an unacceptable $\mathbf{CT_q}$ for those aircraft waiting to be refueled. In contrast, West–18 (MTW) falls into an indeterminate range where a tradeoff must be considered.

Using the static queuing model as a benchmark, supporting West-18 with a single division implies a $\mathbf{CT_q}$ of 6.43 minutes (the time aircraft spend waiting to be refueled). Add another division to support West-18, the ARCP $\mathbf{CT_q}$ would drop dramatically to 0.149 minutes. Adding another KC-130J Division to the ARCP mission provides a significant increase in ARCP capacity ($\mathbf{K\mu}$), as discussed in Chapter II.

During a KC-130J requirements meeting held at Naval Air Station, Patuxent River, the KC-130J community experts felt it relevant to consider the affects of either Allied aircraft or MV-22 assets that may require refueling during an MTW.[47] Section two of the *Marine KC-130 Requirements Study* addresses these affects and includes a 10% increase in the theater arrival rates (λ) in the base case.[48] This thesis increases the

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[47] KC-130J Tanker Requirements meeting held at Naval Air Station, Patuxent River, Maryland; 24 Sep 99.

[48] Gates, William R., Young Kwon, Timothy Anderson, and Alan Washburn; Marine KC-130 Requirements Study, Naval Postgraduate School, Monterey, CA. October 1999. Section #2, p. 40.

arrival rates for East Surge and West-18 by 10%, referred to as East Surge (+10%) and West-18 (+10%) in table 17 (Appendix B). The resulting tradeoff between one and two divisions supporting the West-18 Theater is much greater; ARCP $\mathbf{CT_q}$ is 12.57 minutes with a single division and 0.232 minutes with two KC-130J divisions.

Adding a second division to West-18 (+10%) enables the USMC to meet the five-minute ARCP $\mathbf{CT_q}$ constraint, but the ARCP utilization (ρ) drops by 50%. This means that 42.3% of the time the ARCP is busy, but the ARCP has 57.7% excess $\mathbf{K\mu}$ (ARCP Capacity). Excess capacity will be discussed further in the Cost / Benefit Analysis section of this chapter.

KC-130J Requirements (Day) - STATIC Queuing Model Analysis

Categories							Number of Divisions				KC-130Js		
							1		2		#	Theater	#
Theater	λ per hour	λ (rate) per minute	μ per hour	μ (rate) per minute	P_0	# of Drogues (Channels)	CT_q (min)	INV_q	CT_q (Min)	INV_q	Refueling	Total	Dual MTW
East Surge	35.1	0.585	12	0.2000	0.0422	4	-	-	2.225	1.302	32	48	
West - 18	18	0.300	12	0.2000	0.1429	2	6.43	1.93			16	24	72
West - 18	18	0.300	12	0.2000	0.2210	4	-	-	0.149	0.045	32	48	96
East Surge (+ 10%)	38.6	0.644	12	0.2000	0.0265	4	-	-	3.862	2.485	32	48	
West - 18 (+ 10%)	20.3	0.338	12	0.2000	0.0835	2	12.57	4.25			16	24	72
West - 18 (+ 10%)	20.3	0.338	12	0.2000	0.1811	4	-	-	0.232	0.078	32	48	96

Arrival Rates (λ) per Theater						Refuel Division Capacity (without Droque Failure)							
Theater	t_a	(λ) Arrival Rate	λ per hour	Util (ρ)	# of Divisions	# of Division	# of A/C	Drogues (K)	t_c	Droque Capacity (μ)	ARCP Capacity (Kμ)	Per Hour	Process Time
East Surge	1.709	0.585	35.1	**73.1%**	2	0	0	1	5	0.20	-	12.0	5
West - 18	3.333	0.300	18	**75.0%**	1	1	16	2	-		0.40	24.0	
West - 18	3.333	0.300	18	**37.5%**	2	2	32	4	-		0.80	48.0	
East Surge (+ 10%)	1.554	0.643	38.6	**80.4%**	2								
West - 18 (+ 10%)	2.955	0.338	20.3	**84.6%**	1								
West - 18 (+ 10%)	2.956	0.338	20.3	**42.3%**	2								

Table 17. KC-130J Requirements (Day) – STATIC Queuing Model Analysis

The last three columns in the top schedule of table 17 calculate the number of KC-130Js required to support both the ARCP mission and the other missions for which KC-130Js are tasked. These missions include Direct Air Support Control (Air) [DASC(A)], cargo transport, rapid ground refueling (RGR), and Airborne Standby.[49] Marine Aviation Weapons and Tactics Squadron One (MAWTS-1) projected that the ARCP

[49] Ibid. Section #2, p. 22-24.

mission makes up 66.7% of the USMC KC-130J mission requirements; this percentage is used here.[50] Thus, DASC(A), Cargo Transport, RGR and Airborne Standby make up 33.3% of the USMC KC-130J missions.

In table 17, the column titled KC-130J-Refueling shows the number of KC-130Js required to support that theater's arrival rate (λ) and meet the minimum five-minute ARCP $\mathbf{CT_q}$ constraint. The next column titled "Total" divides the number of KC-130Js required to support the ARCP requirement by 66.7%. This calculates the total number of KC-130Js required to meet all assigned missions in that theater.

Thus, it takes forty-eight KC-130Js to meet the requirements of the East Surge Theater using two KC-130J divisions (second to the last column marked, "Total"). West-18 theater requires twenty-four KC-130Js, if a single KC-130J division supports the ARCP Mission, and forty-eight KC-130Js if two divisions are used. The same calculations are applied to East Surge (+10%) and West-18 (+10%) in table 17.

The final column (Dual MTW) calculates the total number of KC-130Js required to support both theaters, simultaneously. For example, the value for West-18 (row #2) reveals that if the USMC supports East Surge with two divisions and West-18 with one division, seventy-two KC-130Js will be required for all missions in both theaters. If the USMC supports the West-18 theater with two divisions, ninety-six KC-130Js would be needed. Nevertheless, the larger requirement would enable the USMC to meet its five-minute ARCP $\mathbf{CT_q}$ constraint in both theaters. As stated earlier, tradeoffs will have to be made.

Finally, the utilization factors (ρ) in the bottom left of the schedule in table 17, marked as Arrival Rates (λ) per Theater, provide a percentage value showing the percentage of time the ARCP is serving a customer.

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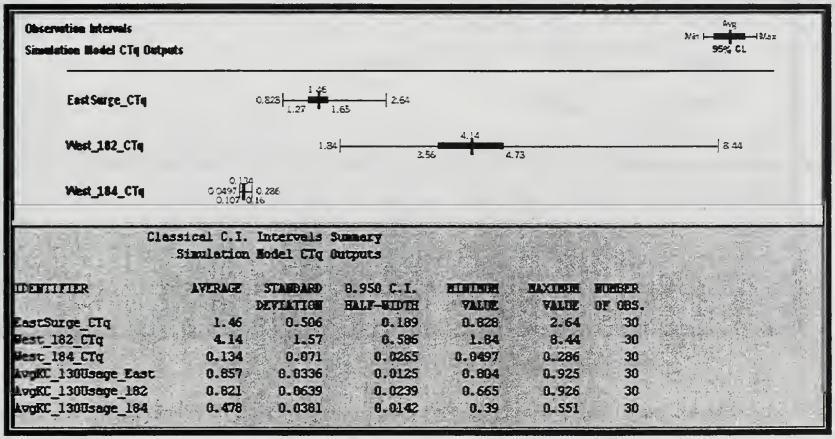
[50] Ibid. Section #2, p. 37.

These factors will be useful later for discussing the tradeoffs between the fleet size required to achieve a certain level of system performance, CT_q and the cost of that fleet. This is addressed in the cost / benefit analysis section of this chapter.

These results can be compared to the ARCP CT_q results from the simulation model given the arrival rates (λ) shown in table 17 for each theater. Figure 15 below contains the simulation results for East Surge, using two divisions to support the ARCP mission, and the results for one and/or two divisions supporting the West-18 ARCP mission. Observe that the simulation results are not the same as the static queuing model for reasons discussed in chapter III. However, the conclusions in some cases are similar to those derived using the static queuing model.



Classical C.I. Intervals Summary
Simulation Model CTq Outputs

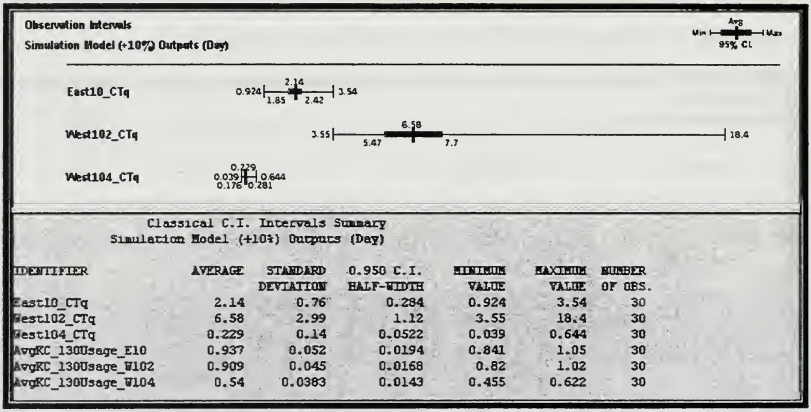
IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
EastSurge_CTq	1.46	0.506	0.189	0.828	2.64	30
West_182_CTq	4.14	1.57	0.586	1.84	8.44	30
West_184_CTq	0.134	0.071	0.0265	0.0497	0.286	30
AvgKC_130Usage_East	0.857	0.0336	0.0125	0.804	0.925	30
AvgKC_130Usage_182	0.821	0.0639	0.0239	0.665	0.926	30
AvgKC_130Usage_184	0.478	0.0381	0.0142	0.39	0.551	30

Figure 15. Simulation Model CT_q Outputs (Day)

The USMC still needs at least two divisions to support the ARCP mission in the East Surge Theater. Further, a single KC-130J division supporting the West-18 ARCP mission provides an average of 4.14 minutes CT_q. With a **95%** confidence level, the true mean ARCP CT_q for the West-18 will fall between 3.56 and 4.73 minutes. Thus, it appears the

West-18 Theater will meet the five-minute ARCP $\mathbf{CT_q}$ constraint without incurring the significant increase of adding another division of KC-130Js.

However, when the arrival rates (λ) for each theater are increased by 10%, the results are different. Figure 16 depicts the outputs of the simulation model using the arrival rates (λ) increased by 10%. Notice again, that the East Surge ($\mathbf{East10_CT_q}$) achieves an average 2.14 minutes $\mathbf{CT_q}$ with two divisions supporting the ARCP mission. However, using one division of KC-130Js to support the West-18 ($\mathbf{West102_\ CT_q}$) ARCP mission provides an average 6.58 minute $\mathbf{CT_q}$; the **95%** confidence interval is entirely above the five-minute ARCP $\mathbf{CT_q}$ constraint.



Classical C.I. Intervals Summary
Simulation Model (+10%) Outputs (Day)

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
East10_CTq	2.14	0.76	0.284	0.924	3.54	30
West102_CTq	6.58	2.99	1.12	3.55	18.4	30
West104_CTq	0.229	0.14	0.0522	0.039	0.644	30
AvgKC_130Usage_E10	0.937	0.052	0.0194	0.841	1.05	30
AvgKC_130Usage_W102	0.909	0.045	0.0168	0.82	1.02	30
AvgKC_130Usage_W104	0.54	0.0383	0.0143	0.455	0.622	30

Figure 16. Simulation Model (+10%) CT_q Outputs (Day)

Thus, the USMC may need to add another KC-130J division to meet the five-minute ARCP $\mathbf{CT_q}$ constraint for the West-18 ($\mathbf{West104_\ CT_q}$) ARCP mission. This represents a significant jump in ARCP capacity ($\mathbf{K\mu}$), driving the ARCP $\mathbf{CT_q}$ down to 0.229 minutes. However, that jump in ARCP capacity ($\mathbf{K\mu}$) significantly increases cost.

This covers the ARCP day operations. Will it be more difficult to execute this AR mission at night? The next section covers ARCP night operations and affects on the KC-130J Fleet size.

C. KC-130J FLEET SIZING REQUIREMENTS NIGHT OPERATIONS

When the ARCP transitions into night refueling operations, the refuel (process) time increases. Actually, refueling the aircraft does not take longer, but the time to engage the aircraft probe and the KC-130J drogue doubles. During night operations the refueling (process) time increases to eight minutes, compared to five-minutes during the day, as shown in Table 18. This assumption was highlighted in Figure 2 at the end of Chapter II.

KC-130J Requirements (Night) - STATIC Queuing Model

Categories							Number of Divisions						KC-130Js		
							1		2		3		4	*Theater*	#
Theater	λ per hour	λ (rate) per minute	μ per hour	μ (rate) per minute	P_0	# of Drogues (Channels)	CTq (min)	INVq	CTq (Min)	INVq	CTq (Min)	INVq	Refueling	Total	Dual MTW
East Surge	35.1	0.585	7.5	0.1250	0.0072	6	-	-			2.697	1.69504	48	72	
West - 18	18	0.300	7.5	0.1250	0.0831	4	-	-	1.435	0.431			32	48	120
East Surge (+ 10%)	38.61	0.644	7.5	0.1250	0.0035	6	-	-			6.026	3.87697	48	72	
West - 18 (+ 10%)	20.3	0.338	7.5	0.1250	0.0568	4	-	-	2.432	0.823			32	48	120

Arrival Rates (λ) per Theater						Refuel Division Capacity (without Drogue Failure)							
Theater	t_a	(λ) Arrival Rate	λ per hour	Util (ρ)	# of Divisions	# of Divisions	# of A/C	Drogues (K)	t_s	Drogue Capacity (μ)	ARCP Capacity (Kμ)	per Hour	*Process Time*
East Surge	1.709	0.585	35.1	**78.0%**	3	0	0	1	8	0.125	-	7.5	8
West - 18	3.333	0.300	18	**60.0%**	2	1	16	2	-		0.25	15.0	
East Surge (+ 10%)	1.554	0.643	38.6	**85.8%**	3	2	24	4	-		0.50	30.0	
West - 18 (+ 10%)	2.956	0.338	20.3	**67.7%**	2	3	32	6	-		0.75	45.0	

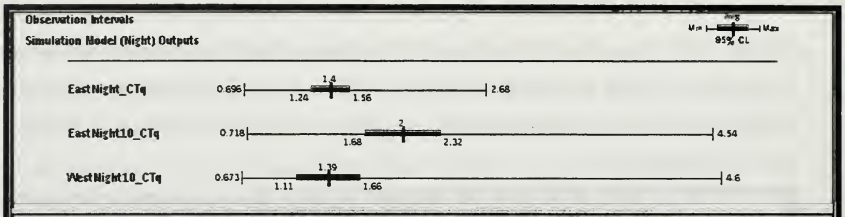
Table 18. KC-130J Requirements (Night) – STATIC Queuing Model Analysis

Notice how the KC-130J Fleet size requirement jumps to three divisions to meet the requirements of the East Surge arrival rate (λ). West-18 requires two divisions for both arrival rates. This provides us with a fleet size of 120 KC-130Js, if we apply the straightline methodology used previously.

Decreasing the number of divisions supporting either theater's ARCP during night operations is not advisable. Any decrease will cause an undesirable increase in the ARCP $\mathbf{CT_q}$, far beyond the five-minute constraint. The increase of the refueling (process) time does have a dramatic affect on the fleet size requirement.

It appears that two divisions adequately support the West-18 and West-18 (+10%) theater scenarios. But the ARCP $\mathbf{CT_q}$ for the East Surge

(+10%) theater exceeds the five-minute constraint. Since, the simulation model better reflects the realistic operations of an ARCP supporting an MTW, we will execute several simulation runs to better understand the KC-130J fleet sizing requirements for night operations.



Classical C.I. Intervals Summary
Simulation Model (Night) Outputs

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
EastNight_CTq	1.4	0.441	0.165	0.696	2.68	30
EastNight10_CTq	2	0.854	0.319	0.718	4.54	30
WestNight10_CTq	1.39	0.727	0.271	0.673	4.6	30
AvgKC_130Usage_EN	1.05	0.0443	0.0165	0.957	1.16	30
AvgKC_130Usage_EN10	1.11	0.0623	0.0232	1	1.24	30
AvgKC_130Usage_WN10	0.885	0.0615	0.023	0.765	1.03	30

Figure 17. Simulation Model (Night) CT_q Outputs

The Simulation Model results in Figure 17 lead to the same ARCP support requirement. Both **EastNight_CT$_q$** and **EastNight10_CT$_q$** reveal that the USMC will need at least three divisions in the eastern theater to meet its night ARCP requirements. **WestNight10_CT$_q$** with the highest arrival rate (λ) (West_18 +10%) for the western theater shows the USMC will require at least two divisions in that theater to meet its ARCP requirements at night. Thus, if we follow the straightline methodology used previously, the USMC would need a KC-130J Fleet size of 120 to assure that it maintains a **CT$_q$** below the five-minute time constraint. However, there may be a less costly alternative than the fleet size of 120 Tankers.

Since we only need the increased ARCP Capacity ($K\mu$) at night, if we add another Division we would not utilize that extra division

efficiently during the daylight hours, as shown in Table 19 below. Notice the highlighted rows in the lower left-hand schedule of Table 19 (the μ factors are in bold print). If the USMC were to purchase three KC-130J Divisions to support the EastSurge Theater utilization (ρ) during the day would fall between forty-seven (47.4%) and fiftyfour (53.6%). This causes an unacceptable amount of excess capacity (μ) (46.4% - 52.6%) during the day. Nevertheless, the USMC still needs the ARCP capacity (**Kμ**) of three KC-130J Divisions to meet its night requirement. However, there may be a cogent alternative.

KC-130J Requirements (Alternative) - STATIC Queuing Model

Categories							Number of Divisions				KC-130J		
							2		3		#	Theater	4
Theater	λ per hour	λ (rate) per minute	μ per hour	μ (rate) per minute	P_0	# of Drogues (Channels)	CT_q (Min)	SIVq	CT_q (Min)	SIVq	Refueling	Total	Dual MTW
East Surge (Day)	35.1	0.585	12.0	0.2000	0.0422	4	2.225	1.302			32	48	
East Surge (Day)	34.1	0.568	12.0	0.2000	0.0576	6	-	-	0.127	0.072	48	72	120
East Surge (Night)	35.1	0.585	7.5	0.1250	0.0072	6			2.897	1.695	40	68	108
East Surge +10%(Day)	38.6	0.644	12.0	0.2000	0.0265	4	3.862	2.486			32	48	
East Surge +10%(Day)	38.6	0.644	12.0	0.2000	0.0391	6	0.000	-	0.233	0.150	48	72	120
East Surge +10%(Night	38.6	0.644	7.5	0.1250	0.0055	6			6.028	3.879	40	68	108

Arrival Rates (λ) per Theater							Refuel Division Capacity (Day)							
Theater	t_a	(λ) Arrival Rate	λ per hour	Util (ρ)	Excess Capacity (μ)	# of Divisions	# of Divisions	# of A/C	Drogues (K)	t_r	Drogue Capacity (μ)	ARCP Capacity (Kμ)	Per Hour	Process Time
East Surge (Day)	1.709	0.585	35.1	73.1%	26.9%	2	0	0	4	8	0.200	-	12.0	5
East Surge (Day)	1.760	0.568	34.1	47.4%	52.6%	3	1	16	2	-		0.40	24.0	
East Surge (Night)	1.709	0.585	35.1	78.0%	22.0%	3	2	32	4	-		0.80	48.0	
East Surge +10%(Day)	1.554	0.644	38.6	80.4%	19.6%	2	3	48	6	-		1.20	72.0	
East Surge +10%(Day)	1.554	0.644	38.6	53.6%	46.4%	3	Refuel Division Capacity (Night)							
East Surge +10%(Night	1.554	0.644	38.6	86.8%	14.2%	3	0	0	1	8	0.125	-	7.5	8
							1	16	2	-		0.25	15.0	
							2	32	4	-		0.50	30.0	
							3	48	6	-		0.75	45.0	

Table 19. KC-130J Requirements (Alternative) – STATIC Queuing Model Analysis

The USMC only needs that excess ARCP (**Kμ**) at night. Refering back to Table 10 or Appendix A, we know that to support an ARCP for a twelve hour period requires eight KC-130Js. Thus, the USMC could save LCC by adding eight more Tankers to the pre-existing EastSurge theater requirement of two KC-130J Divisions. Following the same process as before, we derive a KC-130J Fleet size of 108 (48 + 60/ .6667 = 108) without saddling the USMC with inefficient excess capacity (μ). This

alternative will enable the USMC to efficiently meet the five-minute $\mathbf{CT_q}$ constraint, without incurring excessive costs.

D. KC-130J FLEET SIZING COSTS

With a **95%** confidence level, the costs to achieve an average ARCP $\mathbf{CT_q}$ of 1.46 minutes for East Surge and 4.14 minutes for West-18 will be somewhere between $5.7 and $10.7 (mean = $8.4) billion dollars (FY2000 constant), see Figure 18. This represents the present value of the Life Cycle Costs for a fleet of seventy-two KC-130Js as required to meet the mission needs of both theaters. This fleet requirement uses the ARCP as the primary mission driving the requirement. Yet, a 10% increase in arrival rates (λ) is likely, considering the normal Allied participation in an MTW as well as the influx of aerial refueling capable MV-22s.

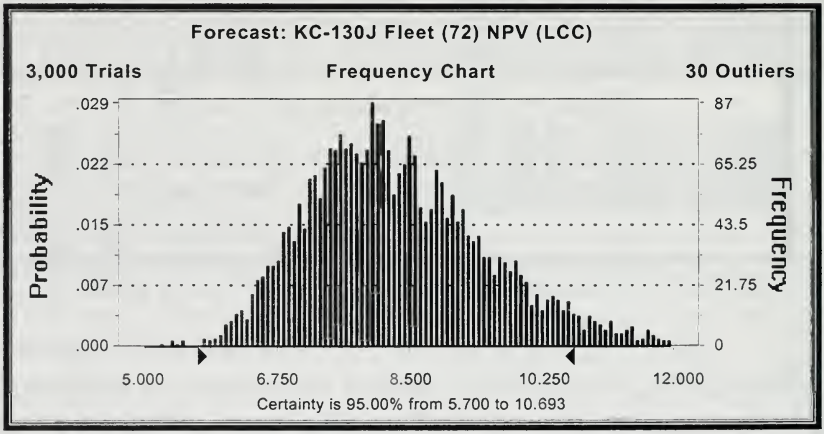


Figure 18. Forecast: KC-130J Fleet (72) NPV (LCC [in billions])

The cost of a 10% increase in the East Surge and West-18 arrival rates (λ) for daytime operations will depend on the tradeoffs made. If the USMC is willing to accept a $\mathbf{CT_q}$ exceeding the five-minute ARCP $\mathbf{CT_q}$ constraint (West-18 ARCP $\mathbf{CT_q}$ = 6.58'), then the present value fleet LCC will be the same as those in Figure 18. However, if the USMC considers

the five-minute ARCP CT_q constraint inviolable (West-18 ARCP CT_q = 0.229'), then the costs will increase to between $6.7 and $14.0 (mean = $10.7) billion dollars (FY2000 constant), as shown in Figure 19.

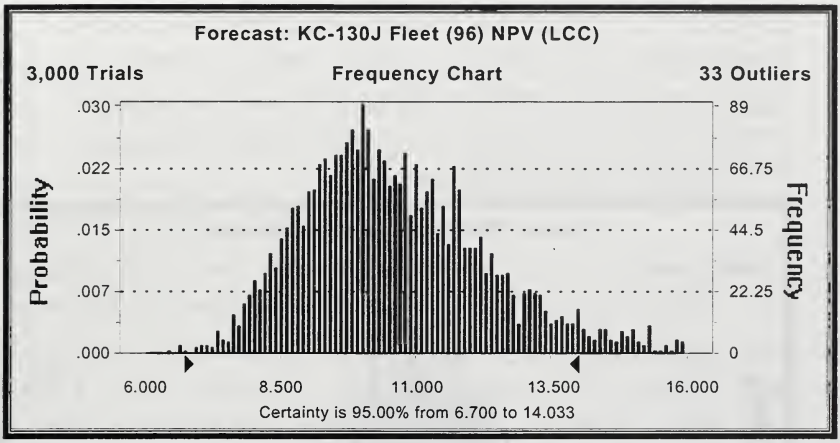


Figure 19. Forecast: KC-130J Fleet (96) NPV (LCC [in billions])

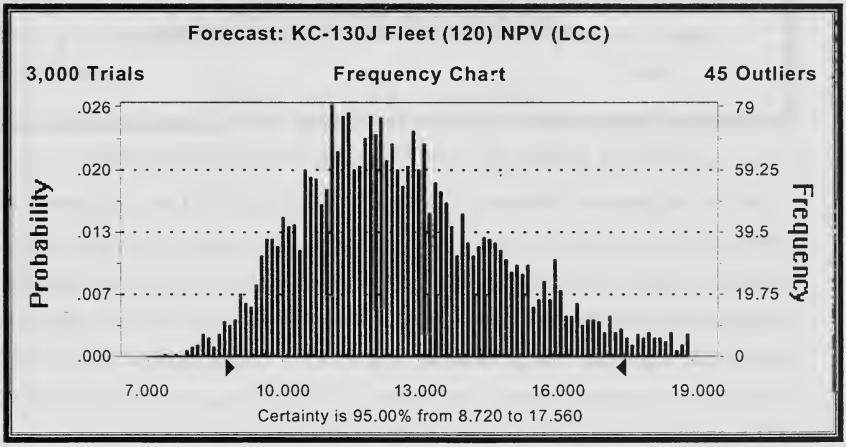


Figure 20. Forecast: KC-130J Fleet (120) NPV (LCC [in billions])

The cost of sustaining $\mathbf{CT_q}$ below the five-minute ARCP $\mathbf{CT_q}$ constraint during night operations will be considerable. At a minimum, a KC-130J Fleet size of 120 tankers will be needed to sustain the $\mathbf{CT_q}$ below five-minutes. This fleet will cost the USMC between $8.7 and $17.6 (mean = $11.2) billion dollars (FY2000 constant), as shown in Figure 20. Yet, this would be an inefficient use of resources, considering the alternative KC-130J Fleet size of 108 tankers, which would still efficiently meet the USMC requirement.

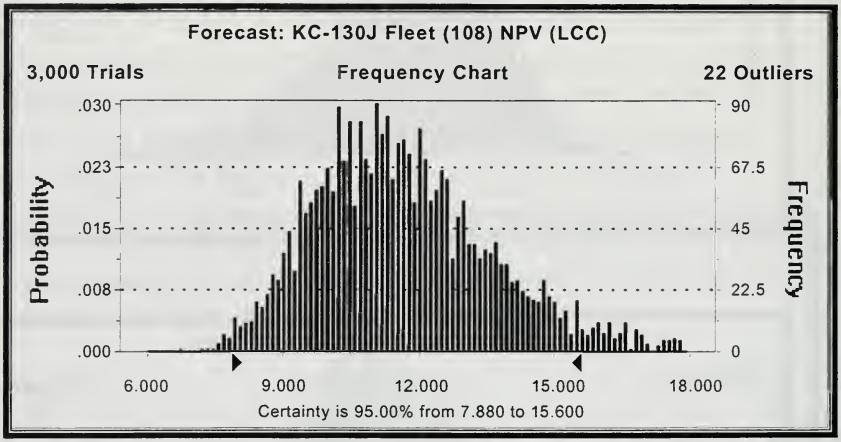


Figure 21. Forecast: KC-130J Fleet (108) NPV (LCC [in billions])

So, ultimately the cost of maintaining the ARCP $\mathbf{CT_q}$ below the five-minute constraint for both day and night operations in both theaters would be a KC-130J Fleet size of 108 tankers. We can be 95% confident the associated cost will be between $7.8 and $15.6 (mean = $11.7) billion dollars (FY2000 constant), refer to Figure 21. The tradeoffs between the various fleet size options can be shown visually to better highlight the cost / benefit relationship.

E. KC-130J FLEET SIZING COST / BENEFIT ANALYSIS

Figure 21 below visually depicts this cost / benefit tradeoff between the various options. With the arrival rates (λ) for daytime operations of 35.1 per hour for East Surge and 18 per hour for West-18, no tradeoff is necessary, unless the USMC wants to consider lowering the ARCP $\mathbf{CT_q}$ below four-minutes for day time operations. However, with Allied and MV-22 demand, the arrival rates (λ) are increased by 10% to 38.6 per hour for East Surge and 20.3 per hour for West-18 during daytime operations. In this case, a tradeoff is implied.

The USMC must decide if the five-minute $\mathbf{CT_q}$ constraint for the West-18 Theater and night operations in both theaters is inviolable. To reveal this difference, the cumulative probability density statistics output report from the Crystal Ball© simulation was used. This generated Figure 21, which shows the difference in cost over the simulation runs for a fleet size of 72, 96, and 108. Using the EXCEL© statistical formulas available, Table 20 was derived to provide a 95% confidence interval around the projected cost difference, assuming the sample derived is normally distributed.

The resulting cost difference has a mean of approximately $2.31 billion dollars with a 95% confidence interval that the actual mean will be between $2.1 and $2.6 billion dollars. Thus, it will cost approximately $2.31 billion dollars to maintain the five-minute $\mathbf{CT_q}$ constraint for the ARCP serving the West-18 (+10%) Theater during daytime operations. Is it worth $2.31 billion dollars to the USMC to ensure ARCP $\mathbf{CT_q}$ for the West-18 (+10%) Theater is less than five-minutes during daytime operations?

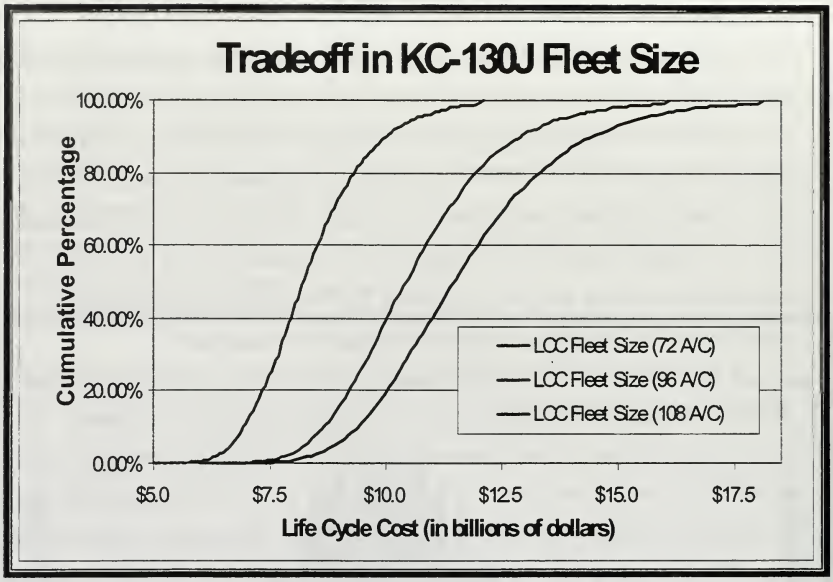


Figure 22. LCC of different KC-130J Fleet Sizes

Between KC-130J Flt Size of 72 vs 96	
Statistical Confidence Interval	
Mean	$2.31
Std Dev	0.562
Conf. Int	95%
Lower	$2.066
Upper	$2.558

Table 20. Statistical Confidence Interval for Fleet Size of 72 vs.96

The same concept was used to determine the cost between a KC-130J Fleet size of 96 verses 108. The cost difference between the two has a mean of approximately $1.1 billion dollars with a 95% confidence interval that the actual mean will be between $0.9 and $1.2 billion dollars. Thus, to sustain ARCP $\mathbf{CT_q}$ below the five-minute constraint for night operations will cost approximately $1.1 billion dollars more than the KC-130J Fleet size of 96.

Between KC-130J Flt Size of 96 vs 108	
Statistical Confidence Interval	
Mean	1.083
Std Dev	0.320
Conf. Int	95%
Lower	$0.942
Upper	$1.223

Table 21. Statistical Confidence Interval for Fleet Size of 96 vs.108

Further, it is crucial to highlight that the decrease in ARCP $\mathbf{CT_q}$ also reduces either utilization (ρ), using static queuing theory, or the Average KC-130J Usage, using the simulation model outputs. In the static queuing model, the Arrival rates (λ) per Theater portion of Table 17 reveals that adding another KC-130J division to the West-18 (+10%) theater drops ARCP utilization (ρ) from 84.6% to 42.3%. The USMC would have 57.7% excess ARCP capacity, vice 15.4% with a single KC-130J division supporting the West-18 Theater. This provides the USMC substantially more flexibility to meet unforeseen contingencies or unexpected surges in demand. Particularly, considering the USMC will need two divisions of KC-130Js to meet its night requirements in the West_18 (+10%) theater, which is a likely scenario.

The bottom portion of Figure 16 contains the corresponding simulation output values. **AvgKC_130Usage_W102** simulates one division, or two drogues, on station supporting the West-18 (+10%) arrival rate (λ); **AvgKC_130Usage_W104** simulates two divisions, or four drogues, on station in this theater. With one division, on average 0.909 (~ 90.9%) of the KC-130Js are being used at any one time; with two divisions, that value drops to 0.54 (~ 54%). Thus, the Average KC-130 Usage results from the simulation model yield the same conclusion. To meet the five-minute ARCP $\mathbf{CT_q}$ constraint for the West-18 (+10%) theater generates a significant drop in ARCP utilization (ρ) or average KC-130J

usage on station. Again, this excess provides the USMC additional flexibility for dealing with unexpected contingencies.

The utilization factors and average KC-130Js in use for ARCP night operations are not as critical. Mainly, because a KC-130J fleet of 108 will enable the USMC to efficiently maintain ARCP $\mathbf{CT_q}$ below five-minutes. Any less than that will cause an unacceptable ARCP $\mathbf{CT_q}$ far above the five-minute constraint. Further, the utilization factor (ρ) in Table 18 are higher than in most scenarios previously analyzed, the lowest ρ for ARCP night operations is 60%.

F. CHAPTER SUMMARY

In this chapter, the ARCP requirement has been clearly defined, focusing primarily on the ARCP $\mathbf{CT_q}$ in a given theater. The critical point occurs when US Armed Forces begin transitioning their aviation assets from the western (West-18) to the eastern (East Surge) theater. The analysis began by discussing purely USMC refueling needs, using the ARCP requirement for day and night operations to define the total KC-130J Fleet size. Further, we increased the arrival rate per theater by 10% to account for potential Allied and MV-22 tanking requirements. Using the LCC model, we calculated the (real) costs associated with the three cases. Finally, we concluded with a cost / benefit analysis attributing a KC-130J Life Cycle Cost to a particular ARCP $\mathbf{CT_q}$ performance achieved. The next chapter draws upon this analysis to state some conclusions and provide some cogent recommendations.

VI. KC-130J FLEET SIZE, CONCLUSIONS AND RECOMMENDATIONS

A. INTRODUCTION

This chapter culminates by defining the estimated KC-130J Fleet size requirement. It draws on the analysis contained in the preceding chapter in making the fleet sizing recommendation. This chapter also includes the conclusions, recommendations, and further issues that should be considered when making the KC-130J Fleet Sizing decision.

B. KC-130J FLEET SIZE CONCLUSIONS

1. The Arrival Rate (λ) of Combat Aircraft to be refueled and the Aerial Refuel Control Point capacity ($K\mu$) in a particular theater are critical to the KC-130J Fleet sizing requirement.

The ARCP Capacity ($K\mu$) must be large enough to handle the theater arrival rate (λ). As discussed in Chapter III, at some point as the utilization factor ($\rho = \lambda / K\mu$) gets closer to one, the queue would increase until all refueling capable aircraft are refueling, in the queue waiting to be refueled, or just leaving the ARCP. Thus, the KC-130J Fleet must have enough tankers continuously on station to ensure the $K\mu$ exceeds λ; the theater thereby avoids excessively large $\mathbf{INV_q}$ and corresponding $\mathbf{CT_q}$ for the ARCP.

2. The Cycle Time of the Aerial Refuel Control Point Queue (CT_q) provides the critical value that ultimately drives the KC-130J Fleet sizing requirement.

The KC-130J Fleet size must be large enough to keep the ARCP $\mathbf{CT_q}$ below five minutes, the defined constraint. Thus, $K\mu$ must be

sufficiently greater than λ to meet the five-minute ARCP $\mathbf{CT_q}$. As clearly defined in Chapter V, a KC-130J Fleet size of seventy-two is required to meet this criteria for with two near simultaneous MTWs. If a 10% increase in the arrival rate (λ) for each theater is expected, the KC-130J Fleet size requirement increases to ninety-six. Further, when the refuel (process) time increases during ARCP night operations the fleet size increases to one hundred and eight.

3. The refuel (process) time proves to be the crucial component that will drive the Aerial Refuel Control Point Capacity needed to meet future USMC requirements.

The aircraft refuel rate, approximately three minutes of the five minute refuel (process) time, ultimately drives $\mathbf{K\mu}$. Any KC-130 platform that on average can refuel combat aircraft in approximately two minutes, subtracting the time it takes aircraft to attach and detach its probe from the KC-130's drogue, provides capacity (μ) similar to a KC-130J. To ensure adequate refueling capacity, the USMC can maintain KC-130 Tankers that provide the same aircraft refueling rate as the KC-130J. This includes the KC-130 R/T variants.

C. KC-130J FLEET SIZE RECOMMENDATIONS

1. The KC-130J Fleet size of 72 Tankers currently meets the USMC aerial refueling requirements.

Currently, a KC-130 Fleet size of seventy-two should be adequate to meet current ARCP requirements, excluding Allied and MV-22 refueling requirements. Based on the analysis in Chapter V, this fleet size is adequate to meet the five-minute ARCP $\mathbf{CT_q}$ constraint for day operations only. However, projecting the aerial refuel requirement into the future considering both day and night operations reveals the potential for those requirements to increase.

2. The KC-130J Fleet size of 108 Tankers will meet future USMC aerial refueling requirements.

Unclassified information received from the recent Kosovo conflict showed a shortfall in aerial refueling assets.[51] Further discussion with KC-130 pilots who served in the Gulf War showed that Allied aircraft often used the Marine KC-130 refueling assets.[52] Thus, the KC-130 Fleet size needed to support future MTW scenarios must increase to provide sufficient ARCP capacity ($K\mu$) to keep the ARCP CT_q below five-minutes.

3. The Fleet size of 108 KC-130J or KC-130J equivalents can meet future USMC aerial refueling requirements.

Since funds for starting up and sustaining a Major Defense Acquisition Program (MDAP) are currently at a premium, the KC-130J Fleet NPV (LCC) of between $7.9 and $15.6 billion dollars will not be easy to justify. However, by procuring enough KC-130Js to retire the older (slower refueling rate) KC-130F and increase the entire USMC fleet of KC-130J/R/Ts to 108 tankers would be a reasonable alternative. Currently, the USMC has fourteen KC-30R variants and twenty-two KC-130T variants.

D. OTHER ISSUES

1. The KC-130J could change current KC-130 Tactics, Technics, and Procedures.

Lieutenant Colonel (LtCol) Arlen Rens, USMC (Ret), the Lockheed-Martin's demonstration pilot for the KC-130J, introduced an interesting

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[51] Telephone interview with Major Patrick S. Flanery, USMC, MAWTS-1 KC-130 Instructor, 02 Sep 99.

[52] Telephone interview with Lieutenant Colonel Arlen Rens, USMC (Ret), former Commanding Officer of the Composite KC-130 deployed in support of OPERATION DESERT STORM, 27 Aug 99.

facet of the KC-130J that may affect the future Tactics, Techniques, and Procedures of the KC-130 Fleet.[53] The KC-130J possesses a probe that makes the KC-130J aerial refueling capable. Currently, the KC-130Js supporting an ARCP must return to their airfield to refuel and refit, taking on average three and half-hours. Instead, the probe capable KC-130J could simply fly to an Air Force KC-10 ARCP and completely refuel; significantly reducing the turn around time required to refuel and refit a KC-130J. This could drastically reduce the number of KC-130Js or KC-130J equivalents necessary to support dual near simultaneous MTWs. This is a potential subject for further analysis.

2. Tradeoff Analysis should be conducted between the KC-130J procurement program and other priority procurement programs.

Every even numbered year, the USMC submits its Program Objective Memorandum (POM) outlining those programs that it requests the Department of Defense to support through the Planning, Programming, and Budgeting System (PPBS). As funding for Major Defense Acquisition Programs (MDAP) becomes more austere, the need for thorough tradeoff analysis between priority procurement programs will become more critical. Certainly, this could be the subject of future research. In particular, research could analyze the tradeoffs between the KC-130J and other priority procurement programs.

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[53] Ibid.

APPENDIX A. 24 HOUR AERIAL REFUEL CONTROL POINT SCHEDULE

24 Hour Aerial Refuel Control Point Schedule

KC-130J A/C #

DAY	Hour #	Time Period (in minutes) From	To	1 Kμ	1 Time	2 Kμ	2 Time	3 Kμ	3 Time	4 Kμ	4 Time	5 Kμ	5 Time	6 Kμ	6 Time	7 Kμ	7 Time	8 Kμ	8 Time	9 Kμ	9 Time	10 Kμ	10 Time	11 Kμ	11 Time	12 Kμ	12 Time	13 Kμ	13 Time	14 Kμ	14 Time	15 Kμ	15 Time	16 Kμ	16 Time
1	0.75	0	45	2	45	0																											
	1.5	45	90	0		2	45	0																									
	2.25	90	135			0		2	45	0																							
	3	135	180					0		2	45	0																					
	3.75	180	225							0		2	45	0																			
	4.5	225	270									0		2	45	0																	
	5.25	270	315											0		2	45	0															
	6	315	360	0												0		2	45														
	6.75	360	405	2	45	0																											
	7.5	405	450	0		2	45	0																									
	8.25	450	495			0		2	45	0																							
	9	495	540					0		2	45	0																					
	9.75	540	585							0		2	45	0																			
	10.5	585	630									0		2	45	0																	
	11.25	630	675											0		2	45	0															
	12	675	720													0		2	45	0													
	12.75	720	765															0		2	45	0		0		0		0		0		0	
	13.5	765	810																	0		2	45	0									
	14.25	810	855																	0		0		2	45	0							
	15	855	900																	0		0		0		2	45	0					
	15.75	900	945																									2	45	0			
	16.5	945	990																	0		0		0		0		0		2	45	0	
	17.25	990	1035																	0		0		0		0		0		0		2	45	0
	18	1035	1080																	0		0		0		0		0		0		0		2	45
	18.75	1080	1125																	2	45	0		0		0		0		0		0	
	19.5	1125	1170																	0		2	45	0		0		0		0		0	
	20.25	1170	1215																			0		2	45	0		0		0		0	
	21	1215	1260																					0		2	45	0		0		0	
	21.75	1260	1305																									2	45	0		0	
	22.5	1305	1350																									0		2	45	0	
	23.25	1350	1395																											0		2	45	0
	24	1395	1440	0																												0		2	45
2	0.75	0	45	2	45	0																										0	
	1.5	45	90	0		2	45	0																									
	2.25	90	135	0		0		2	45	0																							
	3	135	180	0		0		0		2	45	0																					
	3.75	180	225	0		0		0		0		2	45	0																			
	4.5	225	270	0		0		0		0		0		2	45	0																	
	5.25	270	315	0		0		0		0		0		0		2	45	0															
	6	315	360	0		0		0		0		0		0		0		2	45														
	6.75	360	405	2	45	0																											
	7.5	405	450	0		2	45	0		0		0		0		0		0															
	8.25	450	495			0		2	45	0		0		0		0		0															
	9	495	540					0		2	45	0		0		0		0															
	9.75	540	585							0		2	45	0																			
	10.5	585	630									0		2	45	0		0															
	11.25	630	675											0		2	45	0															
	12	675	720													0		2	45	0													
	12.75	720	765															0		2	45	0											
	13.5	765	810																	0		2	45	0									
	14.25	810	855																	0		0		2	45	0							
	15	855	900																	0		0		0		2	45	0					
	15.75	900	945																									2	45	0			
	16.5	945	990																	0		0		0		0		0		2	45	0	
	17.25	990	1035																	0		0		0		0		0		0		2	45	0
	18	1035	1080																	0		0		0		0		0		0		0		2	45
	18.75	1080	1125																	2	45	0		0		0		0		0		0	
	19.5	1125	1170																	0		2	45	0		0		0		0		0	
	20.25	1170	1215																			0		2	45	0		0		0		0	
	21	1215	1260																					0		2	45	0		0		0	
	21.75	1260	1305																									2	45	0		0	
	22.5	1305	1350																									0		2	45	0	
	23.25	1350	1395																											0		2	45	0
	24	1395	1440																													0		2	45

Assumptions:

1) Aircraft will incur a 3.5 Hour turnaround time from mission complete to assignment to another mission.

2) It takes 5.15 from departing ARCP track to return, during a scheduled mission.

3) Each division supporting the ARCP has adds one spare KC-130J in order to meet mission requirements

Conclusions:

1) This schedule contains very little flexibility considering for eny twelve (12) hour period this model will have 62.5% of these essets dedicated to the ARCP mission; thus, you will have between two end three spare aircraft available for use at eny one time. Given that your operational availability will be approximately 80%.

Spare A/C Turnaround Time

A/C #	Hours of Turnaround Time	Time Periods
1	3.75	5
2	6	8
3	8.25	11
4	10.5	14
5	0.75	1
6	3	4
7	5.25	7
8	7.5	10
9	3.75	5
10	8	8
11	8.25	11
12	10.5	14
13	12	16
14	10.5	14
15	8.25	11
16	5.25	7
Mean	6.6	9.1
StdDev	3.1	4.1
Range	0.75 to 12	

APPENDIX B. KC-130J REQUIREMENTS – STATIC QUEUING MODEL SCHEDULES

KC-130J Requirements - STATIC Queuing Model

Categories							Number of Divisions				KC-130Js
							1		2		#
Theater	λ per hour	λ (rate) per minute	μ per hour	μ (rate) per minute	P_0	# of Drogues (Channels)	CT_q (min)	INV_q	CT_q (Min)	INV_q	Refueling
DESERT STORM (CNA-HIGH)	35.1	0.585	12	0.20	0.0422	4			2.225	1.302	32
DESERT STORM (CNA-MED)	20.3	0.338	12	0.20	0.0835	2	12.57	4.25	-	-	16
DESERT STORM (CNA-MED)	20.3	0.338	12	0.20	0.1811	4			0.232	0.078	32

Arrival Rates (λ) per Theater

Theater	t_a	(λ) Arrival Rate	λ per hour	Util (ρ)	# of Divisions
DESERT STORM (CNA-HIGH)	1.709	0.585	35.1	**73.1%**	2
DESERT STORM (CNA-MED)	2.956	0.338	20.3	**84.6%**	1
DESERT STORM (CNA-MED)	2.956	0.338	20.3	**42.3%**	2

Refuel Division Capacity (without Droque Failure)

# of Divisions	# of A/C	Drogues (K)	t_c	Drogue Capacity (μ)	ARCP Capacity (Kμ)	Per Hour	Process Time
0	0	1	5	0.20	-	12.0	5
1	16	2	-		0.40	24.0	
2	32	4	-		0.80	48.0	

KC-130J Requirements (Chapter III)

KC-130J Requirements (Day) - STATIC Queuing Model Analysis

Categories							Number of Divisions				KC-130Js		
							1		2		#	Theater	#
Theater	λ per hour	λ (rate) per minute	μ per hour	μ (rate) per minute	P_0	# of Drogues (Channels)	CT_q (min)	INV_q	CT_q (Min)	INV_q	Refueling	Total	Dual MTW
East Surge	35.1	0.585	12	0.2000	0.0422	4	-	-	2.225	1.302	32	48	
West - 18	18	0.300	12	0.2000	0.1429	2	6.43	1.93			16	24	72
West - 18	18	0.300	12	0.2000	0.2210	4	-	-	0.149	0.045	32	48	96
East Surge (+ 10%)	38.6	0.644	12	0.2000	0.0265	4	-	-	3.862	2.485	32	48	
West - 18 (+ 10%)	20.3	0.338	12	0.2000	0.0835	2	12.57	4.25			16	24	72
West - 18 (+ 10%)	20.3	0.338	12	0.2000	0.1811	4	-	-	0.232	0.078	32	48	96

Arrival Rates (λ) per Theater

Theater	t_a	(λ) Arrival Rate	λ per hour	Util (ρ)	# of Divisions
East Surge	1.709	0.585	35.1	**73.1%**	2
West - 18	3.333	0.300	18	**75.0%**	1
West - 18	3.333	0.300	18	**37.5%**	2
East Surge (+ 10%)	1.554	0.643	38.6	**80.4%**	2
West - 18 (+ 10%)	2.956	0.338	20.3	**84.6%**	1
West - 18 (+ 10%)	2.956	0.338	20.3	**42.3%**	2

Refuel Division Capacity (without Droque Failure)

# of Divisions	# of A/C	Drogues (K)	t_c	Drogue Capacity (μ)	ARCP Capacity (Kμ)	Per Hour	Process Time
0	0	1	5	0.20	-	12.0	5
1	16	2	-		0.40	24.0	
2	32	4	-		0.80	48.0	

KC-130J Requirements (Day) (Chapter V)

KC-130J Requirements (Night) - STATIC Queuing Model

Categories							Number of Divisions						KC-130Js		
							1		2		3		#	Theater	#
Theater	λ per hour	λ (rate) per minute	μ per hour	μ (rate) per minute	P_0	# of Drogues (Channels)	CTq (min)	INVq	CTq (Min)	INVq	CTq (Min)	INVq	Refueling	Total	Dual MTW
East Surge	35.1	0.585	7.5	0.1250	0.0072	6	-	-			2.897	1.69504	48	72	
West - 18	18	0.300	7.5	0.1250	0.0831	4	-	-	1.435	0.431			32	48	120
East Surge (+ 10%)	38.61	0.644	7.5	0.1250	0.0035	6	-	-			6.028	3.87897	48	72	
West - 18 (+ 10%)	20.3	0.338	7.5	0.1250	0.0568	4	-	-	2.432	0.823			32	48	120

Arrival Rates (λ) per Theater						Refuel Division Capacity (without Drogue Failure)							
Theater	t_a	(λ) Arrival Rate	λ per hour	Util (ρ)	# of Divisions	# of Divisions	# of A/C	Drogues (K)	t_c	Drogue Capacity (μ)	ARCP Capacity (Kμ)	Per Hour	Process Time
East Surge	1.709	0.585	35.1	**78.0%**	3	0	0	1	8	0.125	-	7.5	8
West - 18	3.333	0.300	18	**60.0%**	2	1	16	2	-		0.25	15.0	
East Surge (+ 10%)	1.554	0.643	38.6	**85.8%**	3	2	24	4	-		0.50	30.0	
West - 18 (+ 10%)	2.956	0.338	20.3	**67.7%**	2	3	32	6	-		0.75	45.0	

KC-130J Requirements (Night) (Chapter V)

KC-130J Requirements (Alternative) - STATIC Queuing Model

Categories							Number of Divisions				KC-130J		
							2		3		#	Theater	#
Theater	λ per hour	λ (rate) per minute	μ per hour	μ (rate) per minute	P_0	# of Drogues (Channels)	CT_q (Min)	INVq	CT_q (Min)	INVq	Refueling	Total	Dual MTW
East Surge (Day)	35.1	0.585	12.0	0.2000	0.0422	4	2.225	1.302			32	48	
East Surge (Day)	34.1	0.568	12.0	0.2000	0.0576	6	-	-	0.127	0.072	48	72	120
East Surge (Night)	35.1	0.585	7.5	0.1250	0.0072	6			2.897	1.695	40	60	**108**
East Surge +10%(Day)	38.6	0.644	12.0	0.2000	0.0265	4	3.862	2.485			32	48	
East Surge +10%(Day)	38.6	0.644	12.0	0.2000	0.0391	6	0.000	-	0.233	0.150	48	72	120
East Surge +10%(Night)	38.6	0.644	7.5	0.1250	0.0095	6			6.028	3.879	40	60	**108**

Arrival Rates (λ) per Theater							Refuel Division Capacity (Day)							
Theater	t_a	(λ) Arrival Rate	λ per hour	Util (ρ)	Excess Capacity (μ)	# of Divisions	# of Divisions	# of A/C	Drogues (K)	t_c	Drogue Capacity (μ)	ARCP Capacity (Kμ)	Per Hour	Process Time
East Surge (Day)	1.709	0.585	35.1	73.1%	26.9%	2	0	0	1	5	0.200	-	12.0	5
East Surge (Day)	1.760	0.568	34.1	**47.4%**	**52.6%**	3	1	16	2	-		0.40	24.0	
East Surge (Night)	1.709	0.585	36.1	78.0%	22.0%	3	2	32	4	-		0.80	48.0	
East Surge +10%(Day)	1.554	0.644	38.6	80.4%	19.6%	2	3	48	6	-		1.20	72.0	
East Surge +10%(Day)	1.554	0.644	38.6	53.6%	**46.4%**	3	Refuel Division Capacity (Night)							
East Surge +10%(Night)	1.554	0.644	38.6	85.8%	14.2%	3	0	0	1	8	0.125	-	7.5	8
							1	16	2	-		0.25	15.0	
							2	32	4	-		0.50	30.0	
							3	48	6	-		0.75	45.0	

KC-130J Requirements (Alternative) (Chapter V)

APPENDIX C. LIFE CYCLE COST MODEL

Information used in Sensitivity Analysis	
Number of KC-130Js Procured	36
Number of KC-130Js per year	6
Years in Procurement Plan	6
Cost per KC-130J	$ 55.1
SLEP Costs	$ 5.0
% of Cost Growth at 15 years	2%
Discount Rate	3%
Probability of a MTW	12%
Attrit w/	5%
Attrit w/out	0.01%
Expected KC-130J Life Cycle	40 Years
KC-130J Fleet NPV (COSTS)	$ 4,809,549,396
	4,810

"Changing these numbers will effect the entire spreadsheet

O&M Costs per KC-130J (X 10^6)	
Static Costs	0.408
Non-static Costs (creep)	1.886
Total O&M Cost in FY$99 (Constant)	2.294

Static costs remain constant over the life of the KC-130J.

Non-static Costs begin to creep at a rate of 2% a year at the 15 year mark.

Variability Chart

Key External & Policy Variables	Mean	Change	Variability	Distribution
SLEP Costs	$ 5.0	$ 0.50	σ = +/- .5	Normal
% of Cost Growth at 15 years	2%	1%	σ = +/- 1%	Normal
Discount Rate	2.9%	1%	σ = +/- 1%	Normal
Probability of a MTW	12%		from 5% to 14%	Triangular
Attrit w/	5%	2%	σ = +/- 2%	Normal

O&M Difference Schedule	
Cost Lose Newer	$ 4,809,549,396
Cost Lose Older	$ 4,619,770,144
Difference btwn losing old / new	$ 189,779,253
% Difference of old	3.95%

Sensitivity Analysis Sheet

Deployment / PhaseOut Plan								
KC-130J Aerial Refueler								
	without Attrition		with Attrition					
Year	Fielding Plan	Procurement Inv.	MTW	Attrition	KC130Js Losses	Procurement w/Attrit	KC130Js in Ops	PhaseOut Plan
1997	-	-	0	0.00%	-	2	-	-
1998	2	2	0	0.00%	-	3	2	-
1999	3	5	0	0.00%	-	2	5	-
2000	2	7	0	0.01%	-	6	7	-
2001	6	19	0	0.01%	-	6	13	-
2002	6	19	0	0.01%	-	6	19	-
2003	6	36	0	0.01%	-	6	25	-
2004	6	31	0	0.01%	-	6	31	-
2005	6	36	0	0.01%	-	5	36	-
2006	-	36	0	0.01%	-	-	36	-
2007	-	36	0	0.01%	-	-	36	-
2008	-	36	0	0.01%	-	-	36	-
2009	-	36	0	0.01%	-	-	36	-
2010	-	36	1	5.00%	2	2	34	-
2011	-	36	0	0.01%	-	-	36	-
2012	-	36	0	0.01%	-	-	36	-
2015	-	36	0	0.01%	-	-	36	-
2014	-	36	1	5.00%	2	2	34	-
2015	-	36	0	0.01%	-	-	36	-
2016	-	36	0	0.01%	-	-	36	-
2017	-	36	0	0.01%	-	-	36	-
2018	-	36	0	0.01%	-	-	36	-
2019	-	36	0	0.01%	-	-	36	-
2020	-	36	0	0.01%	-	-	36	-
2021	-	36	0	0.01%	-	-	36	-
2022	-	36	0	0.01%	-	-	36	-
2023	-	36	0	0.01%	-	-	36	-
2024	-	36	1	5.00%	2	2	34	-
2025	-	36	0	0.01%	-	-	36	-
2026	-	36	0	0.01%	-	-	36	-
2027	-	36	0	0.01%	-	-	36	-
2028	-	36	0	0.01%	-	-	36	-
2029	-	36	0	0.01%	-	-	36	-
2030	-	36	0	0.01%	-	-	36	-
2031	-	36	0	0.01%	-	-	36	-
2032	-	36	1	5.00%	2	2	34	-
2033	-	36	0	0.01%	-	-	36	-
2034	-	36	0	0.01%	-	-	36	-
2035	-	36	0	0.01%	-	-	36	-
2036	-	36	1	5.00%	2	2	34	-
2037	-	34	0	0.01%	-	-	34	2
2038	-	31	0	0.01%	-	-	31	3
2039	-	36	0	0.01%	-	-	29	2
2040	-	35	0	0.01%	-	-	23	6
2041	-	11	0	0.01%	-	-	17	6
2042	-	11	0	0.01%	-	-	11	6
2043	-	5	0	0.01%	-	-	5	6
2044	-	-	0	0.01%	-	-	-	6
2045	-	-	0	0.01%	-	-	-	-
2046	-	-	0	0.01%	-	-	-	-
2047	-	-	0	0.01%	-	-	-	-
2048	-	-	0	0.01%	-	-	-	-
2049	-	-	0	0.01%	-	-	-	-
2050	-	-	0	0.01%	-	-	-	-
2051	-	-	0	0.01%	-	-	-	-
2052	-	-	0	0.01%	-	-	-	-
2053	-	-	0	0.01%	-	-	-	-
2054	-	-	0	0.01%	-	-	-	-
2055	-	-	0	0.01%	-	-	-	-
2056	-	-	0	0.01%	-	-	-	-

Deployment Attrition Sheet

Life Cycle Cost Analysis:					KC-130J Fleet NPV (LCC)				$ 4,809,549,396	
Year / Category	Year Designator	Procurement w/ attrition	LC-130Js in Operation	Cost of KC-130J	Static Costs	Non-Static Costs	Cost Growth (Lose New)	SLEP Costs	Costs (FY2000)	Cumulative (FY2000) Costs
1997	3	2	0	112.2	-	-	-	-	122.2	122.2
1998	2	0	0	168.3	0.816	3.772	-	-	183.1	305.3
1999	3	2	0	112.2	2.040	9.430	-	-	127.3	432.6
2000	3	2	7	336.6	2.856	13.202	-	-	352.7	785.2
2001	3	2	13	336.6	5.304	24.518	-	-	356.1	1,141.3
2002	2	2	19	336.6	7.752	35.834	-	-	355.1	1,500.4
2003	3	2	25	336.6	10.200	47.150	-	-	361.6	1,861.9
2004	3	2	31	336.6	12.648	58.466	-	-	363.7	2,225.6
2005	3	2	36	280.5	14.688	67.896	-	-	314.7	2,540.3
2006	3	2	36	0.0	14.688	67.896	-	-	69.8	2,609.9
2007	2	0	36	0.0	14.688	67.896	-	-	67.6	2,677.5
2008	3	0	36	0.0	14.688	67.896	-	-	65.7	2,743.2
2009	9	0	36	0.0	14.688	67.896	-	-	63.8	2,807.1
2010	10	0	34	112.2	13.872	64.124	-	-	142.9	2,950.0
2011	14	0	36	0.0	14.688	67.896	-	-	60.3	3,010.3
2012	15	0	36	0.0	14.688	64.049	3.847	10.000	65.7	3,076.0
2013	15	0	36	0.0	14.688	58.065	9.811	10.000	67.3	3,143.3
2014	14	2	34	112.2	13.872	50.114	14.010	10.000	134.2	3,277.4
2015	15	2	36	0.0	14.688	41.357	26.539	30.000	73.3	3,350.7
2016	16	0	36	0.0	14.688	28.332	39.564	30.000	71.3	3,422.0
2017	14	2	36	0.0	14.688	14.797	53.099	30.000	69.2	3,491.3
2018	19	0	36	0.0	14.688	0.737	67.159	30.000	67.3	3,558.5
2019	19	2	36	0.0	14.688	-	79.551	30.000	72.2	3,630.7
2020	30	2	36	0.0	14.688	-	81.142	25.000	68.8	3,698.9
2021	21	2	36	0.0	14.688	-	82.765	0.000	53.5	3,752.4
2022	22	2	36	0.0	14.688	-	84.420	0.000	52.8	3,805.2
2023	23	0	36	0.0	14.688	-	81.325	0.000	49.7	3,855.0
2024	21	2	34	112.2	13.872	-	82.951	0.000	105.3	3,960.2
2025	25	2	36	0.0	14.688	-	89.587	10.000	55.3	4,016.2
2026	26	0	36	0.0	14.688	-	91.379	0.000	50.4	4,066.6
2027	27	2	36	0.0	14.688	-	93.207	0.000	48.9	4,116.5
2028	28	2	36	0.0	14.688	-	89.789	0.000	46.9	4,163.4
2029	29	2	36	0.0	14.688	-	96.972	10.000	33.1	4,216.5
2030	30	2	36	0.0	14.688	-	98.912	0.000	48.2	4,264.7
2031	31	0	36	0.0	14.688	-	96.286	0.000	45.3	4,310.0
2032	32	2	34	112.2	13.872	-	102.908	0.000	91.7	4,401.7
2033	33	2	36	0.0	14.688	-	104.966	0.000	46.6	4,448.3
2034	34	2	36	0.0	14.688	-	107.065	0.000	46.1	4,494.4
2035	35	0	36	0.0	14.688	-	109.206	0.000	45.6	4,539.9
2036	36	0	34	112.2	13.872	-	111.391	0.000	68.8	4,624.8
2037	37	2	34	0.0	13.872	-	107.306	0.000	42.1	4,668.9
2038	38	2	31	0.0	12.648	-	99.799	0.000	37.9	4,704.8
2039	39	0	29	0.0	11.832	-	95.224	10.000	28.1	4,743.2
2040	40	2	23	0.0	9.384	-	77.033	0.000	27.5	4,770.7
2041	14	0	17	0.0	6.936	-	58.076	0.000	20.1	4,790.9
2042	42	2	17	0.0	4.488	-	36.330	0.000	12.9	4,803.8
2043	43	2	0	0.0	2.040	-	17.771	0.000	5.8	4,809.8
2044	44	2	0	0.0	-	-	-	0.000	-	-
2045	45	0	0	0.0	-	-	-	0.000	-	-
2046	46	0	0	0.0	-	-	-	0.000	-	-
2047	47	0	0	0.0	-	-	-	0.000	-	-
2048	48	0	0	0.0	-	-	-	0.000	-	-
2049	49	0	0	0.0	-	-	-	0.000	-	-
2050	50	0	0	0.0	-	-	-	0.000	-	-
2051	51	0	0	0.0	-	-	-	0.000	-	-
2052	53	2	0	0.0	-	-	-	0.000	-	-
2053	53	0	0	0.0	-	-	-	0.000	-	-
2054	54	2	0	0.0	-	-	-	0.000	-	-
2055	55	0	0	0.0	-	-	-	0.000	-	-
2056	56	0	0	0.0	-	-	-	0.000	-	-

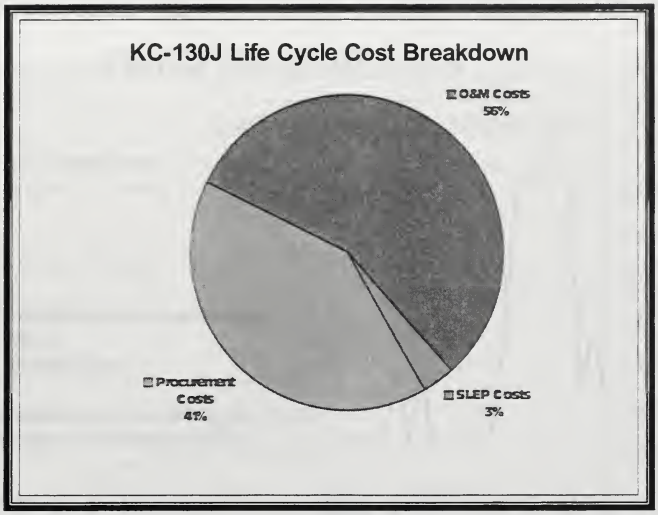
Assumptions:
1) SLEP is done at the 15 year mark.
2) O&M Costs begin to creep at the 15 year mark.

Totals

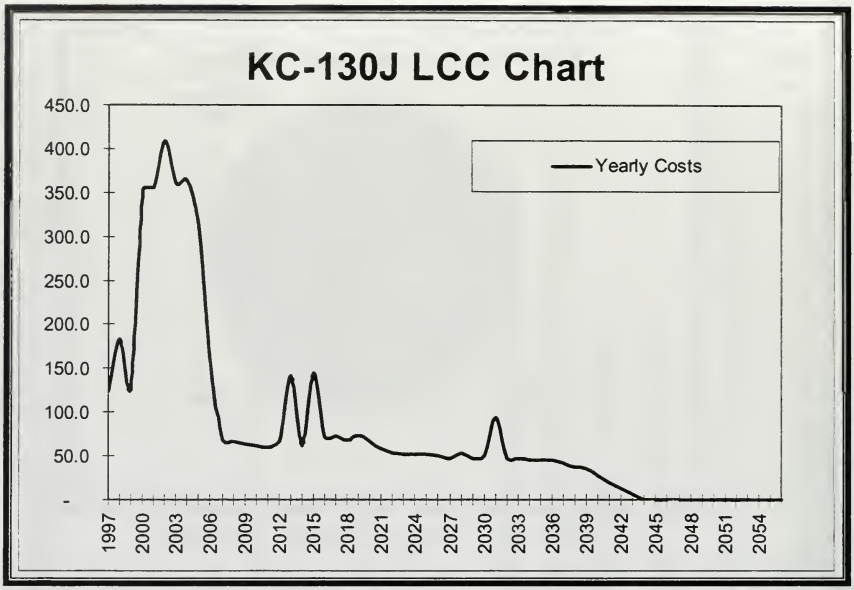
Life Cycle Cost Sheet (Lose New)

Life Cycle Analysis:								KC-130J Fleet NPV (FY2000COSTS)				$ 4,619,770,144		
Year/ Category	Creep-SLEP Time	Year Designator	Number Produced	# w/ Attrition from 15 years back	Number in Operation	New Attrition #s	Total (-) 15year replace	Cost of KC-130J	Static Costs	Non-Static Costs	Cost Growth (Loose Old)	SLEP Costs	Costs (FY2000)	Cumulative (FY2000) Costs
1997	0	3	2	0	0	0	0	112.2	-	-		-	122.2	122.2
1998	1	2	0	2	0	0	0	168.3	0.816	3.772		-	183.1	305.3
1999	2	1	0	0	0	0	0	112.2	2.040	9.430		-	127.3	432.6
2000	3	3	0	7	7	0	0	336.6	2.856	13.202		-	352.7	785.2
2001	4	1	0	13	13	0	0	336.6	5.304	24.518		-	366.1	1,141.3
2002	5	2	0	19	15	0	0	336.6	7.752	35.834		-	369.1	1,500.4
2003	6	3	0	25	25	0	0	336.6	10.200	47.150		-	361.6	1,861.9
2004	7	1	0	31	31	0	0	336.6	12.648	58.466		-	363.7	2,225.6
2005	8	3	0	36	36	0	0	280.5	14.688	67.896		-	314.7	2,540.3
2006	9	6	0	36	36	0	0	0.0	14.688	67.896		-	69.6	2,609.9
2007	10	1	0	36	36	0	0	0.0	14.688	67.896		-	67.6	2,677.5
2008	11	8	0	36	36	0	0	0.0	14.688	67.896		-	65.7	2,743.2
2009	12	3	0	34	36	0	2	0.0	14.688	67.896		-	63.6	2,807.1
2010	13	10	0	34	34	0	2	112.2	13.872	64.124		-	142.9	2,950.0
2011	14	13	0	36	36	0	2	0.0	14.688	67.896		-	60.6	3,010.3
2012	15	12	0	36	36	0	2	0.0	14.688	60.468	7.428	10.000	86.7	3,076.0
2013	16	13	0	36	36	0	2	0.0	14.688	53.824	14.072	15.000	67.3	3,143.3
2014	17	13	2	34	34	0	2	112.2	13.872	43.146	20.978	15.000	134.2	3,277.4
2015	18	15	0	36	36	0	2	0.0	14.688	39.742	28.154	30.000	73.3	3,350.7
2016	19	15	0	36	36	0	2	0.0	14.688	32.287	35.609	30.000	71.3	3,422.0
2017	20	47	0	34	36	0	4	0.0	14.688	25.716	42.180	30.000	69.2	3,491.3
2018	21	13	0	36	36	0	4	0.0	14.688	24.873	43.023	30.000	67.3	3,558.9
2019	22	13	0	36	36	0	4	0.0	14.688	24.012	43.884	30.000	65.4	3,623.9
2020	23	20	0	36	36	0	4	0.0	14.688	23.135	44.761	25.000	60.7	3,684.7
2021	24	21	0	34	36	0	6	0.0	14.688	24.776	43.120	0.000	45.3	3,730.0
2022	25	33	0	36	36	0	4	0.0	14.688	26.501	41.395	0.000	44.0	3,774.0
2023	26	23	0	36	36	0	6	0.0	14.688	23.034	44.862	0.000	42.8	3,816.8
2024	27	24	2	34	34	0	4	112.2	13.872	18.364	45.760	0.000	36.8	3,912.6
2025	28	24	0	36	36	0	4	0.0	14.688	21.221	46.675	10.000	45.3	3,958.9
2026	29	26	0	36	36	0	4	0.0	14.688	23.088	44.808	0.000	39.3	3,997.2
2027	30	27	0	36	36	0	4	0.0	14.688	19.336	48.560	0.000	88.2	4,085.3
2028	31	28	0	36	36	0	4	0.0	14.688	18.364	48.532	0.000	37.1	4,072.4
2029	32	29	0	36	36	0	4	0.0	14.688	20.346	47.550	10.000	40.4	4,112.8
2030	33	30	0	36	36	0	4	0.0	14.688	19.395	48.501	0.000	35.0	4,147.9
2031	34	31	0	36	36	0	4	0.0	14.688	18.425	49.471	0.000	44.0	4,191.9
2032	35	33	0	34	34	0	2	112.2	13.872	13.863	50.461	0.000	76.2	4,268.1
2033	36	34	0	36	36	0	2	0.0	14.688	19.643	48.253	0.000	32.2	4,290.2
2034	37	38	0	36	36	0	2	0.0	14.688	18.678	49.218	0.000	31.2	4,321.8
2035	38	39	0	36	36	0	2	0.0	14.688	-	109.206	0.000	45.6	4,367.0
2036	39	36	2	34	34	0	4	112.2	13.872	12.917	51.207	0.000	68.6	4,435.0
2037	40	31	0	34	34	0	0	0.0	13.872	-	107.306	0.000	42.1	4,477.1
2038	41	38	0	31	31	0	0	0.0	12.648	-	99.796	0.000	37.9	4,515.0
2039	42	34	0	35	35	0	0	0.0	14.630	-	96.224	10.000	38.4	1,853.4
2040	43	40	0	33	33	0	0	0.0	9.384	-	77.033	0.000	27.5	4,581.0
2041	44	47	0	17	17	0	0	0.0	6.936	-	58.076	0.000	20.1	4,601.1
2042	45	12	0	11	17	0	0	0.0	4.488	-	38.330	0.000	12.9	4,614.0
2043	46	13	0	5	0	0	0	0.0	2.040	-	17.771	0.000	5.8	4,619.8
2044	47	48	0	0	0	0	0	0.0	-	-	-	0.000	-	-
2045	48	15	0	0	0	0	0	0.0	-	-	-	0.000	-	-
2045	49	48	0	0	0	0	0	0.0	-	-	-	0.000	-	-
2047	50	47	0	0	0	0	0	0.0	-	-	-	0.000	-	-
2048	51	48	0	0	0	0	0	0.0	-	-	-	0.000	-	-
2049	52	49	0	0	0	0	0	0.0	-	-	-	0.000	-	-
2050	53	50	0	0	0	0	0	0.0	-	-	-	0.000	-	-
2051	54	51	0	0	0	0	0	0.0	-	-	-	0.000	-	-
2052	55	52	0	0	0	0	0	0.0	-	-	-	0.000	-	-
2053	56	53	0	0	0	0	0	0.0	-	-	-	0.000	-	-
2054	57	54	0	0	0	0	0	0.0	-	-	-	0.000	-	-
2055	58	55	0	0	0	0	0	0.0	-	-	-	0.000	-	-
2056	59	56	0	0	0	0	0	0.0	-	-	-	0.000	-	-

Life Cycle Cost Sheet (Lose Old)



KC-130J Life Cycle Cost Breakdown (Chart Sheet)



KC-130K Life Cycle Cost Chart (Chart Sheet)

APPENDIX D. VARIABILITY CHART, CRYSTAL BALL DISTRIBUTION ASSUMPTIONS

Assumption: SLEP Costs Cell: B22

Normal distribution with parameters:

Mean	**$5.0**
Standard Dev.	**$0.5**

Selected range is from -Infinity to +Infinity
Mean value in simulation was $5.0

Assumption: % of Cost Growth at 15 years Cell: B23

Normal distribution with parameters:

Mean	**2%**
Standard Dev.	**1%**

Selected range is from 0% to +Infinity
Mean value in simulation was 2%

Assumption: Discount Rate Cell: B24

Normal distribution with parameters:

Mean	**2.9%**
Standard Dev.	**1.0%**

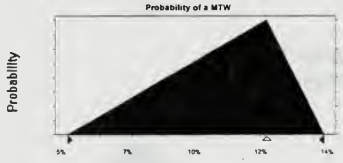
Selected range is from 0.0% to +Infinity
Mean value in simulation was 2.9%

Assumption: Probability of a MTW Cell: B25

Triangular distribution with parameters:

Minimum	**5%**
Likeliest	**12%**
Maximum	**14%**

Selected range is from 5% to 14%
Mean value in simulation was 10%



Assumption: Attrit w/ Cell: B26

Normal distribution with parameters:

Mean	**5%**
Standard Dev.	**2%**

Selected range is from 0% to +Infinity
Mean value in simulation was 5%

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